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Whey Effluent Packed Tower Trickling Filtration

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A theoretically based analysis of BOD removal during flow over an inclined plane and during flow through full-scale trickling filter media has been developed and verified by application to laboratory and full-scale data. The treatability of whey effluent has been demonstrated both by testing with the theoretical model and by comparison with other industrial effluent of known treatability. A computer program was developed for whey treatment, handling series or parallel filtration using one to three stages. The ranges of operating parameters tested were: BOD 200 to 600 ppm; pH 4.5 to 9.8 ; and temperature 15 to 30°C. Filter performance responded primarily to flow changes. Secondary sludge was amenable to thickening by gravity compaction and dewatering by vacuum filtration. Centrifugation was not effective. Combined Village of Walton domestic wastes and whey wastes as of the 1990 projections would comprise 1.17 mgd containing 6860 lbs BOD and 1580 lbs of suspended solids. A $2,749,000 capital cost and a $127,000 annual operating cost are projected for a plant to handle the combined wastes. Waste treatment in a single combined facility rather than separate, ~~individual~~ facilities is expected to realize a 30 to 40% cost savings. (Lowry-Texas) (individual)

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WHEY EFFLUENT
PACKED TOWER TRICKLING FILTRATION

by

Quirk, Lawler & Matusky Engineers
415 Route 303
Tappan, New York 10983

for

Village of Walton
Walton, New York

for the

OFFICE OF RESEARCH AND MONITORING

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ABSTRACT

An analysis of BOD removal during flow over an inclined plane and through full-scale trickling filter media is developed and verified.

A defined scale-up procedure is used to calculate the full-scale reaction rate from the laboratory rate. The former varies with the packing used, the latter is constant.

The treatability of whey effluents is demonstrated by comparison with other industrial effluents, using a Surfpac -like medium in packed towers. A computer program is described, handling series or parallel filtration using one to three stages.

Ranges of operating parameters tested were: BOD 200 to 600 ppm; pH 4.5 to 9.8; temperature 15 to 30°C. Filter performance responded primarily to flow changes. Secondary sludge can be thickened by gravity compaction, and dewatered by vacuum filtration. Centrifugation is not effective.

In comparison, the activated sludge process requires an organic loading less than 0.1 lb. BOD/lb. sludge/day to maintain an SVI under 200, operation is sensitive to all parameters, and neither vacuum filtration nor centrifugation is effective for sludge dewatering.

Process designs and cost analyses are developed for a combination of whey and domestic sewage as follows: flow- 1.17 mgd; BOD - 6,900 lbs/day; suspended solids - 1,600 lbs/day. (Quirk-Quirk, Lawler & Matusky Engineers)

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SECTION I

CONCLUSIONS

Findings and conclusions drawn from the study reported on herein are presented in numerical sequence below.

Theoretical Analyses of Trickling Filtration

1. A theoretically based analysis of BOD removal during flow over an inclined plane and during flow through full-scale trickling filter media has been developed and verified by application to laboratory and full-scale data.

   The analysis is believed to be a new and useful tool in the evaluation and application of packed tower trickling filtration processes in the treatment of organic effluents.

2. BOD changes concentration L_o to concentration L_e after flow over an inclined plane or through a full-scale packed tower has been shown to follow a first order reaction and to be related as follows:

   (a) Inclined plane

   $$\frac{L_e}{L_o} = e^{-k'H/U}$$

   (b) Packed tower (Surfpac or equal)

   $$\frac{L_e}{L_o} = e^{-K_T H/U}$$

   where: H = Tower or plane height in feet

   U = Liquid application rate expressed as: gpm/LF of plane width for laboratory units and gpm/SF of tower area for full-scale units

k' = Specific BOD removal rate constant for effluent treated obtained from laboratory analysis

K_T = BOD removal rate constant for particular packing media used in full-scale tower.

The value of k' is specific and constant for the effluent treated. The value of K_T varies with the type of full-scale packing media used and is computed using the value of k' and the characteristics of the media. A defined scale-up or computational procedure is employed as follows:

$$K_T = k' \cdot A_v \cdot f_t \cdot C_w$$

where: A_v = the specific surface area of manufacturer's packing media

f_t = the fraction of specific surface available as slime area after correction for area reduction due to slime thickness

C_w = a coefficient of efficiency of hydraulic wetting of media.

3. The treatability of whey effluent using the filtration process and plastic sheet flow media has been determined as follows:

k'_{20} = 1.6×10^{-4} gpm/SF for whey @ 20° C

A_v = 27 SF/CF for Surfpac or similar media

f_t = 0.8 for whey

C_w = 0.90 for Surfpac or similar media

and

$$K_T, = 1.6 \times 10^{-4} \times 27 \times 0.8 \times 0.9$$

$$= 0.03 \text{ gpm/CF @ } 20° \text{ C.}$$

4. Using analytical techniques developed by QL&M prior to this study and extended during study execution, literature data for whey application over vertical screens used as trickling filter simulators have been successfully correlated. These data were heretofore uncorrelated in terms of a verified analytical model. The specific rate constant (k') obtained from these data substantiated conclusions reached in this study, i.e., $k' = 1.6 \times 10^{-4}$ gpm/SF @ 20° C.

5. A comparison between the treatability of whey and other industrial effluents using full-scale packed towers and a media similar to Surfpac demonstrates the comparatively high treatability of whey effluent as follows:

Trickling Filtration of Whey
Comparison of BOD Removal Rate Constants

Effluent	K-gpm/CF
1. Integrated Kraft Mill Effluent	.018 to 0.044
2. Ragmill Effluent	.083
3. Boxboard Mill Waste	.027
4. Canning Waste	.021
5. Slaughter House Waste	.044
6. Whey	.030

The rate constants for the non-whey industrial effluents have been determined by application of the analytical model presented in this study to full-scale data from field installations.

Analysis of Laboratory Data

1. The analysis of laboratory data to develop (k') values for the process design of packed tower systems is facilitated by the use of computer programming. A program for the necessary analysis and display of information has been developed and described in this report. The program provides for the inclusion of additional kinetic models other than a first order reaction.

2. The computer program has been designed to accomplish the following purposes:

   (a) Accept laboratory treatment data, execute all unit (dimensional) conversions and print out tabulation of laboratory results.

(b) Prepare tabulations of all process parameters in terms of process design dimensions such as: removal efficiency, recirculation ratio, detention time, temperature, hydraulic loading, etc.

(c) Prepare separate tabulation of the analytical parameters required for evaluation of the kinetic model selected for description of the BOD removal process.

(d) Plot the graphical correlation associated with a given kinetic model and determine, by least squares curve fitting, the values of the process design constants associated with the given kinetic model.

Program subroutines for a first order and a retardant reaction model have been completed. Additional models can be added as required.

Laboratory Equipment

Study results have shown that the performance of trickling filters for whey and other effluents can be accurately duplicated by laboratory equipment utilizing inclined planes.

1. The laboratory apparatus has been demonstrated to be responsive to changes in loading parameters and to be capable of returning to steady state performance rapidly.

2. The laboratory equipment requirements are not complex and can be operated by personnel familiar with waste treatment analyses.

3. Laboratory equipment requirements comprise the following:

    (a) Narrow planes of 1/2 in. width and lengths to 10 ft

    (b) Feed and recirculation pumps

    (c) Heating tapes and temperature controllers

    (d) Refrigeration facilities.

Process Design Calculations

1. The development and comparison of alternative process designs for full-scale packed tower filtration of whey effluents using laboratory data are facilitated by the use of computer programming. A program for the necessary analyses and display of information has been developed and described in this report. The program provides for series or parallel filtration using from one to three stages.

2. The computer program has been designed to accomplish the following:

   (a) Accept waste loading and process design constants as inputs and print out detailed tabulation of process design requirements.

   (b) Prepare detailed tabulation of all major process design elements for each of the kinetic models and alternative process design arrangements selected.

   (c) Process design elements include:

      (1) Removal efficiency per stage

      (2) Area application rate per stage (gpm/SF)

      (3) Recirculation ratio per stage

      (4) Volume of packing media required per stage (CF)

      (5) Total volume of packing media (CF)

      (6) Flow pumped per stage (gpm)

      (7) Total flow pumped - all stages (gpm)

      (8) Number of pumping stations required.

   These printouts allow selection of a process design for minimum cost to achieve a specified degree of treatment.

Packed Tower Performance on Whey Effluent

1. Trickling filter performance is responsive, primarily, to flow changes and has been shown to require a 6 to 8 hour time span to adjust to a 250% change in flow rate when treating whey effluent.

2. The addition of ferrous iron has been shown to be of no demonstrable value in increasing the rate of BOD removal. Significant increases in removal rate can be obtained by nitrogen addition. Nitrogen addition is recommended in process design.

3. In accordance with theoretical predictions, a change in BOD concentration has been demonstrated to have no significant effect on whey BOD removal rate. BOD concentrations examined varied from 200 to 600 ppm.

4. The addition of recirculation will require additional filter volume to produce a given efficiency of BOD removal in the range of removals required for full-scale design. Recirculation flow should be considered in computing filter volume and is not recommended unless required to maintain a minimum wetting velocity for the particular media being employed.

5. pH changes from 4.5 to 9.8 have been evaluated in terms of effects on BOD removal performance. Data indicate an increase in rate constant as pH becomes acidic, e.g., k' @ 9.8 = 1.1×10^{-3} and k' @ 4.5 = 2.8×10^{-3}.

6. Temperature variations from 15 to 30° C have been evaluated in terms of effects on BOD removal performance. Data developed in this study and those obtained from the literature have been shown to follow the Arrhenius relationship:

   $$k''_t = k'_{20} \cdot \theta^{(t-20)}$$

   where θ has been verified as 1.035 for trickling filters.

7. Slime growth has been demonstrated to be prolific and to require that a media of high porosity in the vertical plane be used as a packing media.

8. Pilot plant operation has demonstrated that randomly packed media will cause plugging due to slime sloughing when treating whey effluent. This media is not recommended for design.

9. After trickling filtration, pH may be slightly acidic. This pH may be additionally depressed if the detention time in a conveying sewage system is sufficiently prolonged to cause auto-acidification prior to entry into the treatment plant. Titration requirements for pH adjustments after trickling filtration have been measured and reported on in the study.

10. Suspended solids present in the untreated whey and in the trickling filter effluent have been shown to exhibit a BOD equivalent to 60% of their weight. The achievement of high overall degrees of treatment will require that suspended solids in the final effluent be limited to minimum values.

11. Settling characteristics of trickling filter solids are such as to require coagulant addition in order to insure minimum suspended BOD in the treated effluent.

12. Odor generation from packed tower trickling filters is not anticipated to be highly objectionable at filter loadings required for high BOD removals. However, if deodorization is required, a 10 ppm concentration of ozone has been shown to be an effective control dosage in the air stream passing through the filter.

13. Limited odor protection, consisting of covers for packed towers and forced ventilation, is recommended if units are to be located in the immediate vicinity of odor-sensitive areas.

14. Biological sludge production from trickling filtration is expected to average 0.7 lbs per lb of BOD removed.

Sludge Handling Characteristics

1. Secondary sludge from trickling filtration can be thickened by gravity compaction to an ultimate concentration of 3%. A thickener loading of 6 lbs solids/SF/day is recommended.

2. Solids dewatering by centrifugation is not effective for secondary sludge because of poor recoveries (80%-85%) and low solids content of the dewatered sludge (6%-9%). Chemical addition to increase performance is not economical.

3. Solids dewatering by vacuum filtration can be achieved at a loading of 1.2 lbs/SF/hr using 7% $FeCl_3$ to produce a cake of 20%-25% solids.

4. Polymer addition is not economical when compared with $FeCl_3$ addition for vacuum filtration.

5. The addition of lime did not increase filtration characteristics and in certain cases decreased filterability.

6. Odor generation from the acidified conditioned sludge will require that special ventilation facilities be incorporated in the design of sludge filtration facilities.

Packed Tower and Activated Sludge Comparisons

Process comparisons between packed tower trickling filtration and activated sludge are summarized as follows:

1. In order to maintain an SVI under 200, an organic loading of less than 0.1 lb BOD/lb sludge/day is indicated for activated sludge.

   Bench-scale pilot plant operation indicated a sludge volume index of 145 when operating at a loading of 0.05 lb BOD/lb sludge/day. These low organic loading requirements may be compared with a nominal value of 0.25 lb BOD/lb sludge/day for municipal sewage operation at high degrees of treatment.

2. At an organic loading of 0.1 lb/lb/day, and using a design mixed liquor solids concentration of 2,500 ppm, an aeration detention time of at least 10 hrs per 100 ppm of BOD is required for activated sludge operation at an SVI of 200 or less.

3. At an organic loading of 0.1 lb/lb/day, and a 2,500 ppm mixed liquor, 3 days detention time would be required for the Walton-Breakstone mixture. This volume would be over 4-1/2 times the volume of packed tower.

4. Activated sludge settling characteristics were found to be periodically unstable at SVI values below 200.

5. Flotation of activated sludge mixed liquor, using bench-scale equipment, indicated a design overflow rate of 600 gals/day/SF based on untreated waste flow. Flotation would not be economically competitive in comparison with sedimentation.

6. Activated sludge operation was observed to exhibit significant sensitivity to pH, nutrient and temperature control.

7. Waste sludge solids from the activated sludge process were not amenable to dewatering by vacuum filters or centrifuge.

8. Packed tower trickling filtration is preferred over the activated sludge process.

Treatment of Breakstone and Walton Effluent

1. Process design for the combination of whey from Breakstone Division of Kraftco and the Village of Walton, New York, will be based upon the following design loadings:

Characteristic	1990 Condition
1. Flow	1.17 mgd
2. BOD	6,860 lbs/day
3. Suspended Solids	1,580 lbs/day

2. A BOD removal of 92% of total BOD and 95% of dissolved BOD will be required to comply with New York State effluent requirements. A suspended solids removal of 92% will be required.

3. Minimum cost for packed tower facilities is indicated by two-stage filtration using limited recirculation.

4. Recirculation flow will be returned to the primary sedimentation tanks to provide additional protection against filter plugging, from heavy sloughing. Under normal conditions, filter plugging using Surfpac or equal media is not anticipated.

5. A detailed analysis of capital cost requirements for each of the major design loading parameters was made to estimate changes in cost resulting from changes in design loadings. These values are summarized below for an ENR index of 1540:

   $139,500 per mgd of peak hourly flow
   360,000 per mgd of average daily flow
   272,000 per lb per day of dissolved BOD
   134,000 per lb per day of suspended solids

6. A capital cost (ENR = 1540) of $2,749,000 is estimated for a treatment plant for Breakstone effluent and Walton sewage.

7. An annual operating cost for the initial year of operation is estimated at $127,000 for combined treatment.

8. Charges to Breakstone, based on relative contributions of waste loadings, will approximate 70% of the capital for treatment and 90% of the operating cost for treatment.

9. Combined treatment will reduce total annual costs to Walton by 30% to 40% of that required for an independent municipal sewage treatment plant.

SECTION II

RECOMMENDATIONS

Recommendations based upon study findings are presented below:

1. Theoretical analyses and experimental measurements have resulted in the development of a method of simulating the performance of full-scale, packed tower, trickling filters and scaling-up the results to prototype conditions. Theoretical analyses have been made for two of the five kinetic models which are used to define bio-oxidation. Extension of the work to include the remaining three kinetic models would provide a useful tool for technical personnel involved in the treatment of organic wastes.

2. Computer programming for development of process design parameters for packed tower trickling filters using laboratory data as input has been shown to be an effective methodology. A program for these analyses using two of the five kinetic models available for the description of bio-oxidation processes has been developed in this study. Extension of this effort to include the three remaining kinetic models is recommended.

3. Computer programming for alternative process designs for full-scale application of the trickling filtration process using performance characteristics developed from laboratory equipment has been developed in this study. The program and the analytical work upon which it was based can be employed to define the cost and performance influences of design variables and to optimize full-scale applications. The utility of this effort extends beyond the treatment of whey effluents. It is recommended that an effort be undertaken to extend the program for the purposes of design optimization and/or cost minimization.

4. A laboratory simulation technique for packed tower trickling filtration of organic effluents has been developed and presented in this report. The methodology employed can be of significant assistance to other investigators involved in the evaluation of trickling

filtration of organic effluents. It is recommended that study results be effectively promulgated to investigators active in the field.

5. A method of analysis of full-scale trickling filters has been developed which allows determination of the specific BOD removal rate constant of the effluent and the hydraulic characteristics of the packing or filter media. A determination of these process design parameters for prototype units currently in operation could result in a standardization of treatability descriptions for trickling filters similar to that available for activated sludge. Application of the analysis to full-scale data is recommended for this purpose.

6 The trickling filtration process, using media similar to Surfpac, has been shown to be an effective and operable treatment process for whey effluent from Breakstone, Inc. in combination with domestic sewage from the Village of Walton, New York. It is recommended that this process be employed for full-scale design.

SECTION III

INTRODUCTION

The processing and manufacturing of dairy products is one of the most widespread of all industries in the United States. More than 20 million cows produce over 100 billion pounds of milk yearly. A portion of the production is manufactured into cheese and other dairy products. Many manufacturing operations are located in small communities in or near the rural milk production areas. Waste waters from milk operations are characterized by high putrescibility, high oxygen demand, and the production of poor settling sludges following biological treatment.

Waste waters containing whey from the manufacture of cheese are notorious for causing waste treatment problems, whether treated alone or in conjunction with other wastes including domestic sewage. In addition to possessing high putrescibility, whey may also present problems of pH control and nutrient deficiencies in biological treatment processes.

Recovery by evaporation and drying is the most satisfactory solution to the problem of waste whey. The recovered whey solids may be incorporated in foods or in feeds, or may be used for the manufacture of by-products. However, recovery is a fractional proposition that misses about one-fifth of the production that escapes as dilute rinse water. The rinse waters characteristically possess several times the strength of domestic sewage and have been reported to induce problems at domestic activated sludge plants when present at a level as low as 11% of the total BOD load. Parenthetically, the consensus is that the treatment of dilute whey is facilitated by the dilution and the improved nutrient balance offered by mixture with domestic sewage.

When significant dairy processing operations are located in small communities, the resulting industrial waste may contribute more pollutional load than the entire domestic population. Under such circumstances, domestic sewage treatment design criteria are inapplicable as evidenced by a history of process problems, nuisance conditions and stream pollution.

The Breakstone Foods Division of Kraftco maintains a large cottage cheese manufacturing operation at Walton, New York.

The industry and the Village of Walton are tributary to the west branch of the Delaware River, with the industrial BOD loading being grossly larger than that of the Village. Since practical considerations relative to available space dictate joint treatment, and no applicable treatment process was available, the situation constituted an ideal project for the development of a treatment process widely applicable to whey-bearing wastes.

Purpose and Scope

The Village of Walton was awarded WQO, EPA Research and Development Grant No. 11060 DJJ, and Quirk, Lawler & Matusky Engineers were retained to execute the study. Supplemental support to the project was to be provided by the Breakstone Foods Division of Kraftco and the State of New York Department of Health. The purpose of the project was the development of activated sludge and biological filtration processes applicable to the treatment of whey-bearing wastes. The scope included the determination of mathematical models of process performance, the preparation of computer programs for process design, and the evaluation of methods for dewatering secondary sludges.

As the project progressed, uncertainties relative to committed support necessitated revision of scope. Since biological filtration studies were under way, practicality dictated elimination of the proposed activated sludge studies. To partially compensate for the paring of the activated sludge studies, reference to results of previous activated sludge studies on similar waste is included in the report.

Previous Studies

Although waste treatment problems associated with whey-bearing waste are frequently referenced in milk processing and waste treatment literature, there have been relatively few published studies of formal treatability investigations. Wasserman [37] investigated the utilization of whey as a substrate for yeast culture. The following analysis was presented as representative of whey from the manufacture of cottage cheese.

Component	Percentage
Total Solids	6.0
Ash	0.3
Lactose	4.0
Lactic Acid	0.5
Available Nitrogen	0.033

Optimum yeast yields of 0.57 lbs of yeast per lb of lactose present were obtained at pH 4.7 to 5.0, with supplementation of nutrient nitrogen.

The results of treatability studies with activated sludge have been reported by several authors. Jasewicz and Porges [17, 24] attributed the pronounced tendency of the culture to bulk to nutrient deficiencies that included nitrogen as well as other unspecified growth factors. Adamse [1] observed that process response was more rapid at pH 5 than in the more neutral range from pH 6 to 8.

The treatment of domestic sewage-whey mixtures by the extended aeration and contact stabilization modifications of the activated sludge process was investigated by Quirk, Lawler & Matusky Engineers [25]. The processes were indicated to possess unstable culture characteristics and pronounced dewatering problems were experienced with the waste sludges.

Adverse experience was reported by Maloney et al. [21] relative to the introduction of whey into sewage stabilization ponds. Culture changes, poor performance and odor evaluation were attributed to the presence of whey in the influent waste.

Significant contributions to the waste treatment literature have been made relative to the application of biological filtration to the treatment of whey-bearing wastes. Schulze [29, 30, 31] employed laboratory test stands to obtain data for verification of descriptive mathematical formulations. He also observed culture growth characteristics.

Ingram [15, 16] operated a deep filter pilot plant biological filter on whey-bearing waste. He advocated hydraulic loadings in excess of 70 mgd to insure complete distribution and to maintain freshness. Results were obtained showing 67% removal of BOD at a loading of 300 p t c f d. Under the prescribed operating conditions, odor problems were not encountered.

Theory

The classic trickling filter comprises a bed of stone media over which attached biological slime growths develop. Removal of BOD is obtained by aerobic processes at the slime surface and by anaerobic processes within the slime interior. Packed tower modifications to the trickling filter introduced plastic geometric packing media to obtain increased surface area and porosity. Current practice employs a lattice structure similar to an egg carton insert. BOD removal performance is related to process parameters using an analytical model descriptive of the biological relation observed and the hydraulics of the reactors.

The theory of BOD removal by trickling filter slime over a reaction surface similar to an inclined plane has not been fully developed in the existing engineering literature. Design formulations in current use have been developed by empirical methods and/or by analogy to formulation used to describe the exertion of BOD in general. The work presented herein is based upon a detailed development and verification of the reaction model for trickling filtration previously developed by QL&M and extended for the purposes of this study.

The theoretical development is presented in the following sequence.

1. General model for removal
2. Specific model for selected bio-kinetics
3. Influence of recirculation
4. Influence of temperature
5. Graphical solution
6. Scale-up to full-scale tower.

General Model

General model for BOD removal on an inclined plane surface is developed by the solution of a material balance statement in which the hydraulics of liquid flow and the kinetics of biological reaction have been defined.

A schematic of an inclined plane system is shown on Figure 1.

The material balance statement is written thus:

INPUT - OUTPUT - REMOVAL = ACCUMULATION

INPUT and OUTPUT terms are self-explanatory. The REMOVAL term is defined by the geometry of the reactor and the kinetics of the BOD removal reaction. The ACCUMULATION term accounts for the change in the quantity of BOD stored in the reactor volume. For inclined plane surfaces and trickling filters this storage is negligible in relation to reactor throughput.

The terms of the material balance statement are defined as follows:

INPUT = $(Q+R)L_o$

OUTPUT = $(Q+R)L_e$

REMOVAL = K_rV_r

ACCUMULATION = 0

where:

Q = Untreated flow - gpm

R = Recirculation flow - gpm

L_o = BOD concentration as applied to reactor - ppm

L_e = BOD effluent concentration - ppm

V_r = Volume of reactor - gals.

K_r = A generalized BOD removal rate constant - ppm/min

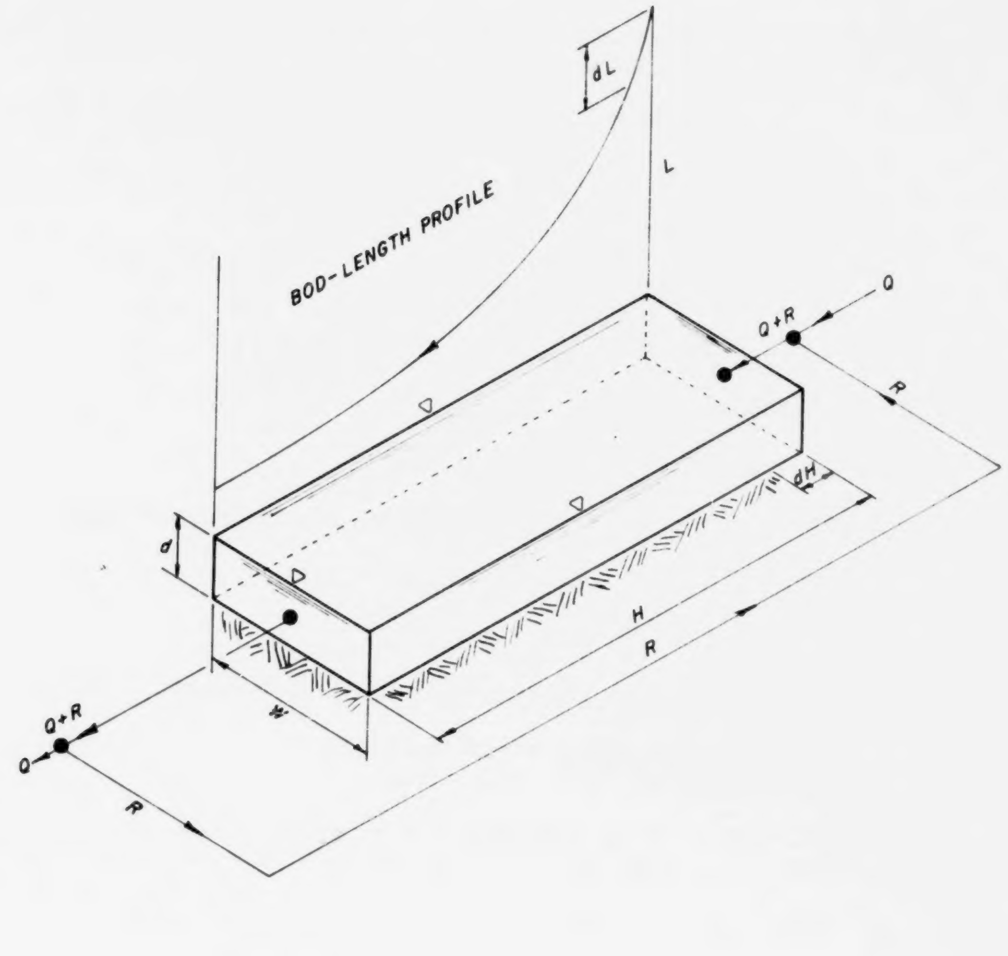
For convenience, the unit conversion factor 1 lb/gal./120 ppm has been excluded from all terms.

The material balance expression is examined over a differential element of plane height (dH) as follows:

$$dV_r = (d)(W)(dH) \qquad (\#1)$$

SCHEMATIC REPRESENTATION BOD REMOVAL OVER SLIMED SURFACE

FIGURE 1


dL
L
BOD-LENGTH PROFILE
Q
Q+R
R
dH
d
H
R
W
Q+R
Q
R

The conversion factor 7.48 gals./CF has been omitted from (#1) for convenience.

BOD reduction over the differential of reactor height is expressed as (dL).

The material balance is then re-expressed in differential terms as follows:

$$\frac{dL}{dH} = \frac{K_r(d)(W)}{(Q+R)} \text{ ....(\#2)}$$

The term (Q+R)/W is conveniently grouped as a hydraulic loading per unit of plane width (U') as follows:

$$\frac{dL}{dH} = \frac{(K_r)(d)}{(U')} \text{ ....(\#3)}$$

Equation (#3) is the general solution for BOD removal over a slimed surface.

Specific Model for First Order Reaction

At this juncture, biological reaction kinetics may be introduced to develop a specific reaction model, i.e., first order, retardant, etc. A first order reaction has been found to apply to trickling filter reaction.

First order kinetics define the generalized rate constant (K_r) in terms of organism concentration and BOD remaining as follows:

$$K_r = (k)(S)(L) \text{ .... (\#4)}$$

where:

k = a specific biological reaction rate constant - 1/ppm x min

S = effective organism concentration - ppm

L = BOD remaining at a point - ppm

The effective organism concentration in a trickling filter is defined in terms of the mass of organisms per unit volume of liquid over the slimed surface as follows:

$$S = \frac{(A_s)(f_w)}{(A_s)(d)} = \frac{f_w}{d} \text{ .... (\#5)}$$

The conversion factor 7.48 gals./CF has been omitted from (#5) for convenience.

where: A_s = area of slime

f_w = a constant for the weight of effective bio mass per unit of slime area

Substitution of the above definition for effective organism concentration into the expression for the first order rate constant equation (#4) yields the following:

$$K_r = (k)(f_w)\frac{(L)}{(d)} = \frac{(k)'(L)}{(d)} \quad \ldots\ldots\ldots \quad (\#6)$$

where:

$k' = (k)(f_w)$

The differential equation (#3) may now be defined in terms of a first order reaction as follows:

$$\frac{dL}{dH} = \frac{k'L}{U'} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (\#7)$$

Integration of the above expression provides the basic analytical relationship for BOD removal over an inclined surface:

$$\frac{L_e}{L_o} = e^{\frac{-k'H}{U'}} \text{ or } \frac{L_o}{L_e} = e^{\frac{k'H}{U'}} \quad \ldots\ldots\ldots\ldots \quad (\#8)$$

The second form of equation (#8) which employs a positive (+) value for the exponential term is preferred in that subsequent graphical solution techniques become more convenient to apply.

Influence of Recirculation

The ratio (L_o/L_e) describes the change of BOD as applied to the slime and therefore includes the effects of recirculation. For design utilization, BOD changes related to the untreated BOD concentration, i.e., BOD removal efficiency, are required.

The change in BOD is related to removal efficiency based on the untreated BOD by a material balance as follows:

$$\frac{L_o}{L_e} = \frac{1 + r\ (1-E)}{(1+r)(1-E)} = f \text{.............} \quad (\#9)$$

where:

r = recirculation ratio R/Q

E = BOD removal efficiency

The factor (f) is introduced for topographical simplicity.

Influence of Temperature

The effect of temperature on reaction rate is introduced using the Arrhenius relationship.

$$k'_t = k'_{20}\theta^{\Delta T} \text{.........................} \quad (\#10)$$

where:

k'_t = reaction constant at temperature t

k'_{20} = reaction constant at standard temperature, 20°C

ΔT = reaction temperature differential °C-20

θ = constant, usually taken as 1.035

Graphical Analysis of Plane Performance

The analysis equation for plane performance is completed as follows:

$$f = e^{k'_{20}\theta^{\Delta T}H/U'} \text{..................} \quad (\#11)$$

A graphical solution to equation (#11) is obtained by taking logarithms as follows:

$$\log\ (f) = \frac{[k']}{[2.3]}\ \frac{[H\theta^{\Delta T}]}{[U']} \text{...........} \quad (\#12)$$

A plot of data on semi-log paper will provide a linear correlation with slope equal to (k'/2.3) and an intercept of

$\log(f) = 1.0$ at $H\theta^{\Delta T}/U' = 0$ as shown on Figure 2. The graphical technique is employed in the analysis of test data.

Scale-Up Relationship for Full-Scale Tower

Conversion to full-scale tower conditions is made by adjusting plane performance for the following:

1. Hydraulic loading of full-scale tower
2. Slime thickness anticipated
3. Surface area characteristics of packing media
4. Hydraulic characteristics of packing media

Hydraulic loading in a full-scale tower is expressed in terms of aerial units and is related to plane hydraulics by geometry considerations as follows:

$$U = (U')/(A_V'') \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (\#13)$$

where:

U = application rate to tower in gpm/SF of tower surface area

U' = application rate to plane in gpm/LF of plane width

A_V'' = slimed area of tower packing media in SF/CF of tower volume

Slime thickness reduces exposed surface area below that available from clean unslimed media. A knowledge of media configuration and slime thickness can be employed to determine the correction required as follows:

$$A_V'' = (A_V')(f_t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (\#14)$$

where:

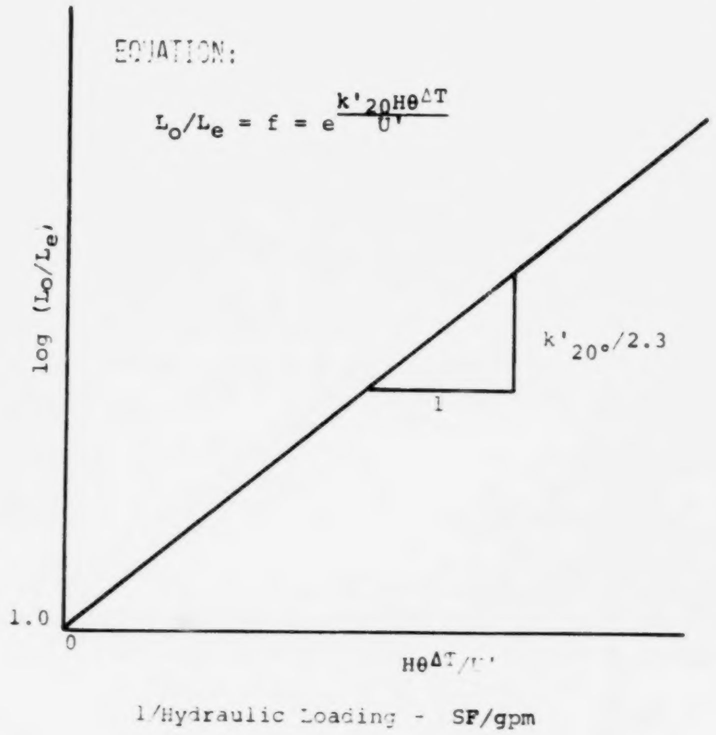
A_V' = wetted area of tower packing media supporting a slime growth

f_t = a factor for the reduction of slime area below that of media area due to thickness of slime growth

FIGURE 2

GRAPHICAL SOLUTION OF SLIMED PLANE BOD REMOVAL PERFORMANCE EQUATION

FIRST ORDER REACTION



Laboratory observations of slime thickness indicated an f_t value of 0.80 when using Surfpac media on whey wastes.

Hydraulic characteristics of packing media are introduced by relating the wetted surface area A'_v and the tower reaction rate to hydraulic loading of the tower.

Adjustments of this type are required primarily for packing media and an "as-packed" geometry other than that obtained with a sheet flow media similar to Surfpac. The adjustments account for the change in wetted areas which occurs as liquid impinges upon randomly packed media and is splashed or otherwise diverted into contact with additional media surface which would otherwise remain unslimed. Additional adjustment can also be made for the possible changes in apparent reaction rate as a result of a change in the rate of transport of BOD from the flowing liquid to the slime surface. This latter change can also include the effects of removal of suspended BOD by agglomeration processes.

For randomly packed media, adjustments for hydraulic effects can be made using a mathematical form prevalent in the chemical engineering field when packed towers are analyzed, i.e.:

$$\frac{A'_v}{A_v} \sim (U)^n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (\#15)$$

and

$$\frac{(k'')}{(k')} \sim (U)^n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (\#16)$$

Substitution of the above scale-up (#11) relationships into the equation for plane performance yields the relationship for full-scale tower performance as follows:

$$e^{[k'_{20} \cdot A_v \cdot f_t \cdot C]\frac{H\theta^{\Delta T}}{(U)^n}} = f\ldots\ldots \quad (\#17)$$

where:

C = a combined constant for hydraulic effects.

The value of the exponent n will vary from a minimum of 0.50 for randomly packed media similar to gravel to 1.0 for packing similar to vertical sheets.

For Surfpac or similar media, these adjustments are not considered necessary in that a sheet flow regimen dynamically similar to that of plane hydraulics is maintained over the media. However, an adjustment is made for use of less than total media volume resulting from poor distribution hydraulics through the tower. A constant relationship of 90% tower media utilization is employed as follows:

$$\frac{A_V'}{A_V} = C_w = 0.90 \ldots\ldots\ldots\ldots\ldots\ldots \quad (\#18)$$

where:

A_V' = wetted surface area - SF/CF

A_V = manufacturer's rating for dry media - SF/CF

C_w = a coefficient for wetting efficiency

For Surfpac, or similar media, the value of the hydraulic coefficient C equals C_w and the design relationship is stated as follows:

$$f = e^{K_{20}} \frac{H\theta^{\Delta T}}{U} \ldots\ldots\ldots\ldots\ldots\ldots \quad (\#19)$$

where:

$$K_{20} = k_{20}' \cdot A_V \cdot f_t \cdot C_w$$

The identical form of equation (#17) and the current practice design equation for packed tower trickling filters is noted.

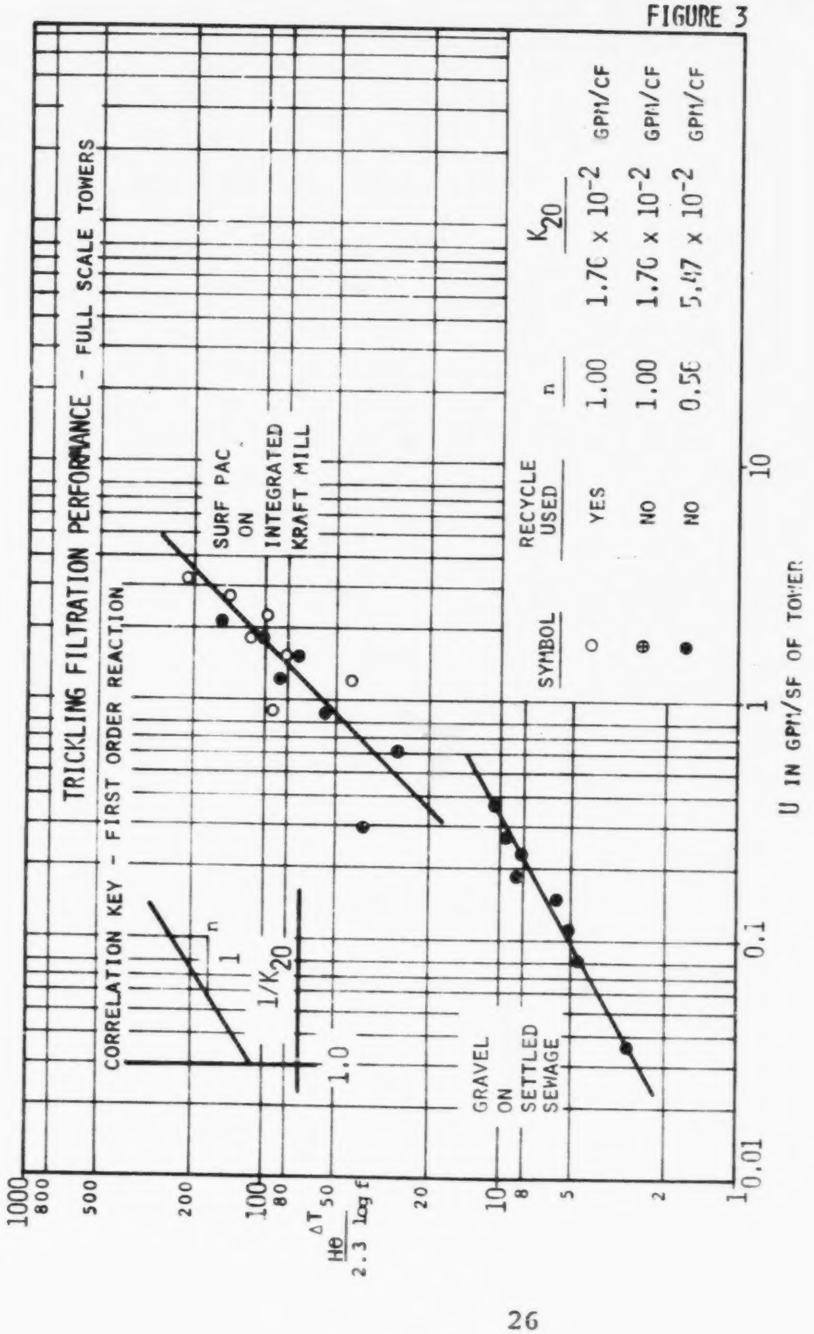
A graphical solution to equation (#17) is obtained by taking logarithms as follows:

$$\log \frac{[\ (H\theta^{\Delta T})\ ]}{[\ (2.3)(\log f)\ ]} = n(U) + \frac{1}{K_{20}} \quad \ldots \ (\#20)$$

A plot of full-scale data on log-log paper will provide a linear correlation with slope equal to (n) and an intercept at U = 1.0 equal to $1/K_{20}$. The graphical technique is employed in the analysis of test data.

Graphical illustrations of tower performance analyzed in accordance with equation (#19) are presented in Figure 3.

FIGURE 3



TRICKLING FILTRATION PERFORMANCE - FULL SCALE TOWERS

SYMBOL	RECYCLE USED	n	K_{20}
○	YES	1.00	1.70×10^{-2} GPM/CF
⊕	NO	1.00	1.70×10^{-2} GPM/CF
●	NO	0.56	5.47×10^{-2} GPM/CF

Additional Kinetic Models

Kinetic models other than a first order reaction have been employed to describe biological oxidation. While less popular than the first order assumption, these additional models have been found to correlate bio-oxidation data in a successful manner. Because of a lack of theoretical model development in the area of trickling filter analyses, these models have been applied primarily to non-fixed bed reactors such as activated sludge, aerated stabilization basins, etc.

The theoretical relationships for packed towers presented above have been extended to include kinetic processes other than first order as follows:

1. Retardant with BOD concentration
2. Zero order

Description of these kinetic models and the correlation techniques developed for their application follow below.

Simple Retardant Reaction Model

In a simple retardant reaction, the rate of BOD removal per unit weight of organisms is proportional not only to the BOD concentrations remaining but also to the fraction or percentage of BOD remaining. Rates of removal decrease, or retard, rapidly as high efficiencies of removal are approached. The kinetic statement is written as follows:

$$K_r = (k')(S)(L)(L/L_o) \quad \ldots\ldots\ldots\ldots\ldots \quad (\#21)$$

After integration, the completed equation for slimed plane analysis is written as follows:

$$f = 1 + \frac{k' \cdot H}{U'} \quad \ldots\ldots\ldots\ldots\ldots \quad (\#22)$$

After scale-up to full-scale conditions, the general packed tower relationship is written as follows:

$$f = 1 + \frac{K_T \cdot H}{(U)^n} \quad \ldots\ldots\ldots\ldots\ldots \quad (\#23)$$

Graphical techniques to be used in correlating data for plane and tower performance are illustrated on Figure 4.

Zero Order Reaction

In a zero order reaction, the rate of BOD removal per unit weight of organism is constant and is not affected by concentration, degree of removal, etc.

The kinetic statement is written as follows:

$$K_r = (k')(S) \ldots\ldots\ldots\ldots\ldots\ldots (\#24)$$

After integration, the completed equation for slimed plane analysis is written as follows:

$$\frac{(E)(L_a)(U')}{(1+r)(H)} = k' \ldots\ldots\ldots\ldots\ldots\ldots (\#25)$$

The expression is simplified by expressing terms on the left side as an organic loading (OL) of untreated BOD per unit area of slime, i.e.:

$$OL = \frac{(L_a)(U')}{(1+r)(H)} \ldots\ldots\ldots\ldots\ldots\ldots (\#26)$$

In terms of organic loading, the slimed plane relationship is stated as follows:

$$(E)(OL) = k' \ldots\ldots\ldots\ldots\ldots\ldots (\#27)$$

After scale-up to full-scale conditions, the packed tower relationship may also be stated in terms of organic loading for an n value = 1.0 as follows:

$$(E)(OL) = K_T \ldots\ldots\ldots\ldots\ldots\ldots (\#28)$$

When packing geometry and/or hydraulics are not such as to yield n = 1.0, the full-scale tower relationship is re-expressed as follows:

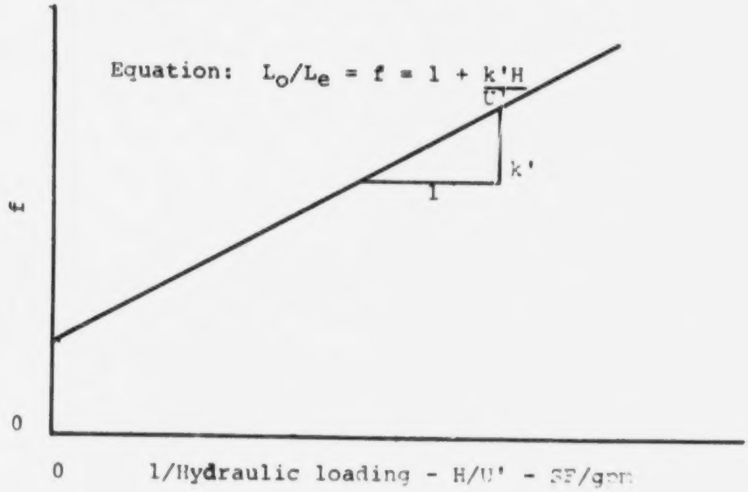
$$\frac{(L_r')}{(H)}(U^n) = K_T \ldots\ldots\ldots\ldots\ldots\ldots (\#29)$$

L_r' = the BOD removal through the tower including the dilution effect of recirculation = $EL_a/(1+r)$

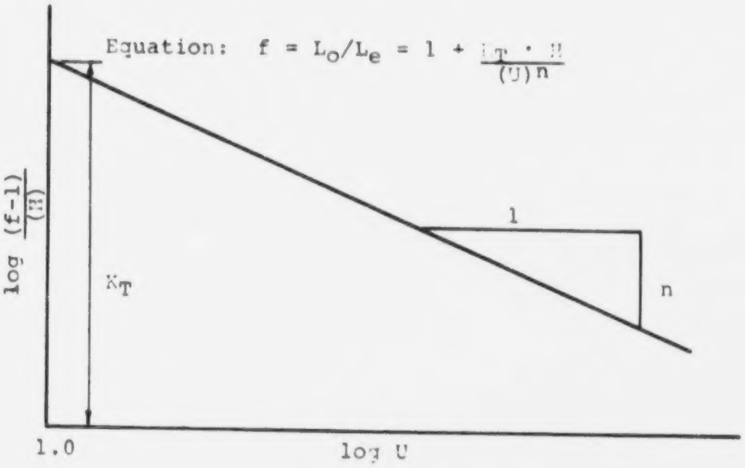
FIGURE 4

Retardant Model Correlations

Analysis of Slimed Plane



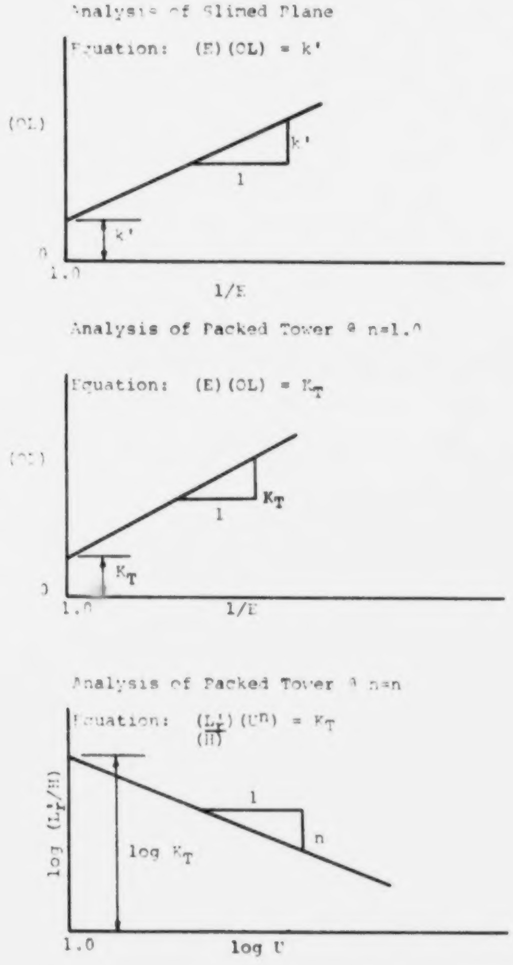
Analysis of Packed Tower



Graphical techniques to be used in correlating data for plane and tower performance are illustrated on Figure 5.

Zero Order Model Correlations

FIGURE 5



SECTION IV

CONSTRUCTION AND PROCESS DESIGN

The object of waste treatment process development is to obtain an understanding of the response of the process to conditions encountered during prototype operation. Since the influence of operational variables is most effectively assessed under controlled conditions, it follows that laboratory studies feature the attribute of efficiency. Parenthetically, some variables are not amenable to evaluation unless the scale of the operation is sufficiently large to be analogous to prototype operations. The present study attempted to employ the attributes of both concepts by utilization of carefully controlled laboratory conditions for evaluation of performance variables and utilization of a 7 gpm on-site pilot plant for generation of sufficient secondary sludge for practical evaluation of dewatering and disposal characteristics.

Efficiency of Removal

Table 1 presents the combined effluent loadings and characteristics for the whey and sewage mixture.

Table 2 presents the requirements for treated effluent and the percent removal of suspended solids, and BOD necessary to comply.

A dissolved BOD removal of 95% is required to reduce BOD concentration to acceptable levels.

Tower Rate Constant

Surfpac or similar media are selected for design.

Equation (#19) is employed to determine the rate constant for BOD removal at 20°C as follows:

$$(K_T) = k' \cdot A_V \cdot \xi_t \cdot C_W \ldots\ldots \quad (\#30)$$

where:

k'_{20} = 1.6×10^{-4} gpm/SF for whey sewage

A_V = 27 SF/CF for Surfpac

TABLE 1

Treatment of Whey and Sewage
Combined Loadings

Characteristic	Initial Condition	1990 Conditions
1. Flow - mgd	1.08	1.17
- gpm	750	815
2. Suspended Solids - lbs/day		
Total	1,790	1,580
Volatile*	1,560	1,260
Inert	230	320
3. Suspended Solids - ppm		
Total	198	162
Volatile*	173	129
Inert	25	33
4. BOD - lbs/day		
Total	4,920	6,860
Suspended**	1,125	1,000
Dissolved	3,795	5,860
5. BOD - ppm		
Total	545	705
Suspended**	125	102
Dissolved	420	603

*Estimated from laboratory analysis of synthetic waste.
**Based on 0.63 lbs BOD/lbs SS as measured in laboratory.

TABLE 2

Treatment of Whey and Sewage
BOD Removal Required

Characteristic	Initial Condition	1990 Conditions
I. Effluent Required		
1. Suspended Solids - ppm	45	45
2. BOD - ppm		
Total	60	60
Suspended	28*	28*
Dissolved	32	32
II. Percent Nominal Removals		
1. Suspended Solids		
Influent	198	168
Effluent	45	45
Removal	153	123
Percent	77.2%	73.2%
2. Total BOD		
Influent	542	730
Effluent	60	60
Removal	482	670
Percent	88.9%	91.8%
3. Dissolved BOD		
Influent	391	623
Effluent	32	32
Removal	359	591
Percent	91.8%	94.9%

**Based on 0.63 lbs BOD/lbs SS as measured in laboratory.*

f_t = 0.8 for whey and sewage

C_W = 0.90 for Surfpac

and K_T = $1.6 \times 10^{-4} \times 27 \times 0.8 \times 0.9$

= 0.03 gpm/CF

Table 3 presents a comparison between the design rate constant K_T = 0.03 for the whey-sewage mixture and rate constants found applicable to other industrial effluents.

Filter Volume and Geometry

For a given type of packing, tower volume can vary with the following design parameters:

1. Liquid application rate
2. Recycle
3. Tower height
4. Efficiency of BOD removal

The effects of variations in the first three parameters are dependent upon the necessity to maintain a minimum wetting rate and the numerical value of the constant (n). In all cases, an increase in efficiency of removal requires an increase in tower volume. In general, the effects of design parameters can be described as follows:

Design Variable	Change in Variables	Change in Tower Volume
H	Increase	Decrease or no change
r	Increase	Increase
U	Increase	Increase
E	Increase	Increase

Structural requirements and hydraulic distribution problems limit maximum tower height. Heights of 20 ft are common with maximums to 45 ft.

Commercial packing of the lattice structure type appears to require minimum application velocities of 1.0 gpm/SF. Operation below the minimum velocity can result in progressively less utilization of tower packing.

TABLE 3

Trickling Filtration of Whey and Sewage Comparison of BOD Removal Rate Constants

Effluent and Media	n	K_{20}/gpm/CF
I. Surfpac Media		
1. Integrated Kraft Mill Waste	1.00	.021
2. Integrated Kraft Mill Waste	1.00	.022
3. Integrated Kraft Mill Waste	1.00	.017
4. Integrated Kraft Mill Waste	1.00	.014
5. Integrated Kraft Mill Waste	1.00	.018
6. Integrated Kraft Mill Waste	1.00	.034
7. Integrated Kraft Mill Waste	1.00	.044
8. Ragmill Effluent	1.00	.083
9. Boxboard Mill Waste	1.00	.027
10. Canning Waste	1.00	.021
11. Slaughter House Waste	1.00	.044
12. Whey and Sewage	1.00	.030
II. Random Pack Media (Gravel)		
1. Dilute Black Liquor	0.57	.051
2. Settled Sewage	0.56	.055

In order to maintain commonly used heights and provide a minimum application velocity, effluent recycle is usually required for high BOD removal efficiencies. The added tower volume required to accommodate recycle varies with the efficiency of removal sought.

Because of the non-uniform influences of design variables, process design calculations involve relatively complex manipulations.

Tower Volume

Equation (#19) is rearranged to determine the wetting application rate (U) for tower operation using Surfpac or similar media without recirculation (U_o) as follows:

$$U_o = \frac{K_T \cdot H}{2.3 \cdot \log'_{(1-E)}} \ldots\ldots\ldots\ldots\ldots\ldots (\#31)$$

A maximum tower height of 42 ft is selected to minimize potential recirculation requirements, and application rates are examined for parallel and series operation of filters. Series operation will reduce total tower volume requirements but will require additional pumping. Application rates and stage removal efficiencies for single and multi-stage designs are tabulated below:

	Single Stage	Two-Stage	Three-Stage
1. Efficiency/Stage - E%	95	77.5	65
2. Application Rate Without Recirculation - U_o gpm/SF	0.42	0.85	1.23

Recirculation would be required on the single and two-stage plants. Recirculation ratios are determined using equation (#9) as follows:

$$r = \frac{\frac{(1)}{(1-E)} - (f)}{(f - 1)} \ldots\ldots\ldots\ldots\ldots\ldots (\#32)$$

The value of (f) is determined by substitution into equation (#19) using a minimum application velocity $U_m = 1.0$ gpm/SF.

A tabulation of recirculation requirements versus stage design is then shown below:

		Single Stage	Two-Stage	Three-Stage
1.	Efficiency/Stage - E%	95	77.5	65
2.	Application Rate - U_o gpm/SF	1.0	1.0	1.23
3.	Recycle Ratio Required - r	6.6	0.4	0

A modification of the basic tower formulation is now used to relate design variables and to determine tower volume requirements.

The modification is achieved by expressing tower volume requirements as a volume per unit of untreated flow (V') and relating this unit volume to process variables.

A basic geometric identity is used to develop a definition for unit volume (V') as shown below.

By flow balance:

$$(1+r)Q = \frac{V \cdot U}{H}$$

and

$$V' = \frac{V}{Q} = (1+r)\frac{(H)}{(U)} \ldots\ldots\ldots\ldots\ldots\ldots \text{(\#33)}$$

Unit volume requirements when recirculation is not required (V_o') are determined from equation (#33) by setting r = 0 and substituting the value of application rate (V_o) from equation (#31) as follows:

$$V_o' = \frac{2.3 \log (1/1-E)}{K_T} \ldots\ldots\ldots\ldots\ldots \text{(\#34)}$$

where:

V_o' = CF of tower volume/gpm of untreated effluent when tower is not recycled

Unit volume requirements for a recirculation reactor must be increased over that for a non-recirculated design and are determined from equation (#33) by setting $U = U_{min}$, e.g., 1.0 gpm/SF, and substituting the value of r as defined in equation (#32). The design equation is stated as follows:

$$(V') = \frac{[H]}{[U_{min}]} \cdot \frac{[E]}{[(1-E)(f-1)]} \cdots\cdots\cdot \quad (\#35)$$

A summary of unit volume requirements versus stage design is shown below:

		Single Stage	Two-Stage	Three-Stage
1.	Efficiency/Stage - E%	95	77.5	65.0
2.	Application Rate - U and U_o gpm/SF	1.0	1.0	1.23
3.	Recycle Ratio - r	6.6	0.4	0
4.	Unit Volume - V_o' and V' CF/gpm	320	116.8	102
5.	Total Volume CF/gpm*	256,000	91,000	80,000
6.	Organic Loading - Lb BOD/1,000 CFD	22.8	64.5	73.0

**Includes unit volume of all stages.*

Because of the high BOD removal required, a multi-stage plant is necessary to reduce tower volume. In the multi-stage design sedimentation of recycle flow prior to tower application is indicated to reduce media plugging tendency. Increased sedimentation capacity is then necessary for a two-stage design. Using a nominal design recirculation ratio of 0.5 for two-stage, the total flow pumped, however, is equal for a two- and a three-stage design, i.e., 3Q. A comparison of the total capital cost for two- and three-stage design alternatives for sedimentation, recycle pumping stations, and trickling filters was made as follows (ENR = 1540):

1.	Two-Stage	$606,000
2.	Three-Stage	596,000

The cost saving for a three-stage design is within the accuracy of cost estimation and, thus, not significant. In order to eliminate a third pumping station as a maintenance center, the two-stage design is selected.

Sludge Disposal Facilities

A material balance for waste treatment plant sludge solids is presented in Table 4.

TABLE 4

Treatment of Whey and Sewage
Material Balance for Sludge Disposal

(In Lbs/Day)

Description	Initial Condition	1990 Condition
1. Influent SS	1,790	1,580
2. Effluent SS	- 405	- 420
3. Difference	1,385	1,160
4. Biological Solids Produced	2,525	3,900
5. ST Raw and Biological Solids	3,910	5,060
6. Conditioning Chemicals	275	355
7. ST Conditioned Solids	4,185	5,415
8. Lime Precipitate	1,440	1,500
9. Total Solids for Disposal	5,625	6,915

Under 1990 conditions, 5,060 lbs/day of raw and biological solids from various conventional treatment units require disposal. An additional 1,500 lbs/day of chemical precipitate are anticipated as the result of lime addition to the final clarifier. Lime addition is included to adjust effluent pH and to increase final clarifier solids removal by coagulation. Enhanced final clarifier solids removal is required to insure compliance with treated effluent BOD concentration limitations. The provision for ferric chloride addition prior to dewatering increases solids loadings, e.g., 355 lbs/day. Total solids aggregate 6,915 lbs/day.

Waste solids disposal will employ dewatering and landfill. Thickening of primary and secondary solids prior to dewatering will be required.

Based upon thickening studies, a solids loading of 6.5 lbs/SF/day can be used to achieve an underflow solids concentration of 3.0%. A total thickener area of 1,070 SF will be required to process the design solids loadings of 6,915 lbs/day.

Sludge dewatering will be obtained by vacuum filtration. Laboratory and pilot plant studies indicate the use of a filter loading of 1.2 lbs/SF/hr. Selection of a 6 hr/day filtration schedule will require two 500-SF vacuum filters. Special ventilation facilities will be included to control odor levels in the filtration room.

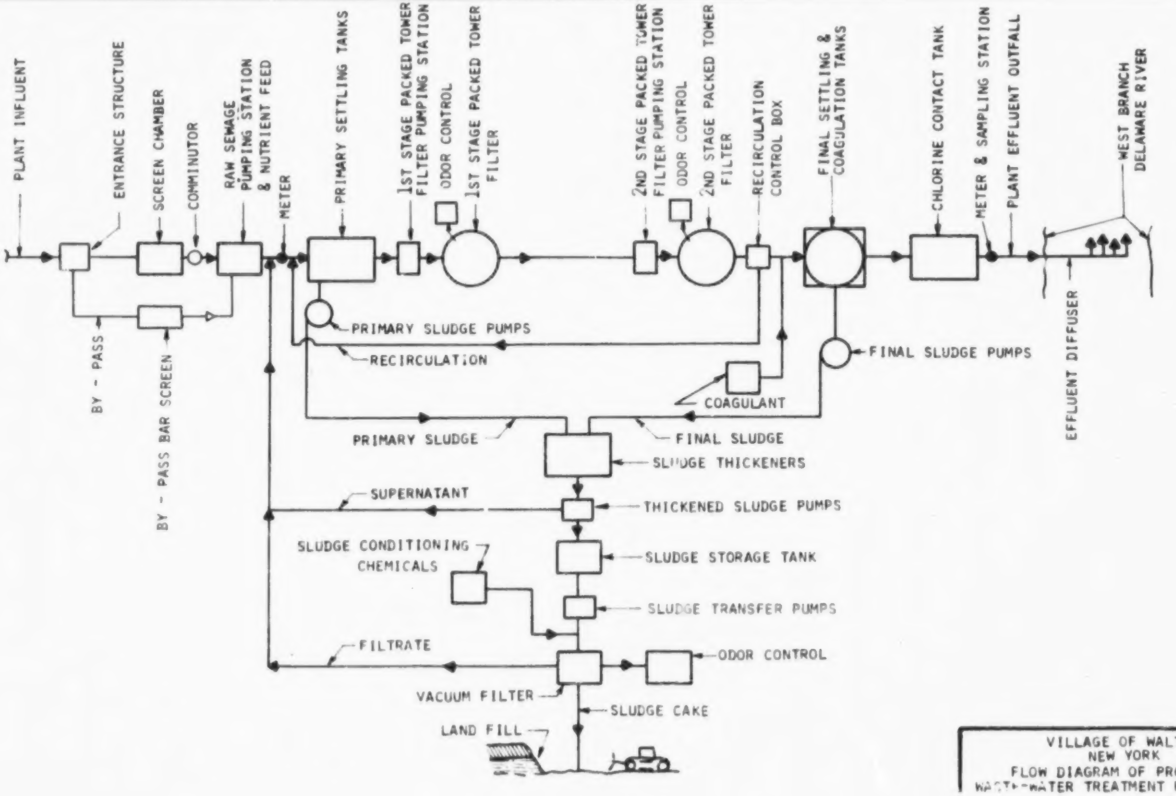
Process Description (Proposed Flow Sheet)

A schematic flow diagram of the recommended waste water treatment facilities is shown on Figure 6. The system employs primary settling, two-stage packed tower trickling filters, final settling, coagulation, sterilization by chlorination, and sludge dewatering.

The major process units are as follows:

1. Entrance structure
2. Mechanically cleaned bar screen
3. Comminutor
4. Screen by-pass
5. By-pass bar screen
6. Raw sewage pumping station and nutrient feeding system

FIGURE 6


PLANT INFLUENT
ENTRANCE STRUCTURE
SCREEN CHAMBER
COMMINUTOR
RAW SEWAGE PUMPING STATION & NUTRIENT FEED
METER
PRIMARY SETTLING TANKS
1ST STAGE PACKED TOWER FILTER PUMPING STATION
ODOR CONTROL
1ST STAGE PACKED TOWER FILTER
2ND STAGE PACKED TOWER FILTER PUMPING STATION
ODOR CONTROL
2ND STAGE PACKED TOWER FILTER
RECIRCULATION CONTROL BOX
FINAL SETTLING & COAGULATION TANKS
CHLORINE CONTACT TANK
METER & SAMPLING STATION
PLANT EFFLUENT OUTFALL
WEST BRANCH DELAWARE RIVER
EFFLUENT DIFFUSER
BY - PASS
BY - PASS BAR SCREEN
PRIMARY SLUDGE PUMPS
RECIRCULATION
FINAL SLUDGE PUMPS
COAGULANT
PRIMARY SLUDGE
FINAL SLUDGE
SLUDGE THICKENERS
SUPERNATANT
THICKENED SLUDGE PUMPS
SLUDGE CONDITIONING CHEMICALS
SLUDGE STORAGE TANK
SLUDGE TRANSFER PUMPS
FILTRATE
ODOR CONTROL
VACUUM FILTER
SLUDGE CAKE
LAND FILL

VILLAGE OF WALTON
NEW YORK
FLOW DIAGRAM OF PROPOSED
WASTE-WATER TREATMENT FACILITIES

PACKED TOWER FILTER

QUIRK, LAWLER & MATUSKY ENGINEERS
NEW YORK, NEW YORK

7. Meter
8. Primary settling tanks
9. Primary sludge pumps
10. 1st stage packed tower filter pumping station
11. 1st stage packed tower filter
12. 2nd stage packed tower filter pumping station
13. 2nd stage packed tower filter
14. Recirculation control box
15. Final settling and coagulation tanks
16. Coagulant feed system
17. Final sludge pumps
18. Chlorine contact tank and chlorination system
19. Effluent metering station
20. Plant effluent outfall
21. Effluent diffuser
22. Sludge thickeners
23. Thickened sludge and supernatant pumps
24. Mixed sludge storage tank
25. Sludge transfer pumps
26. Vacuum filter assembly and sludge dewatering building
27. Sludge conditioning equipment
28. Odor control equipment
29. Sludge handling equipment

30. Control and administration building

31. Emergency power generator

Grit removal facilities have not been provided because the raw waste is anticipated to contain virtually no grit and digesters (requiring grit protection) are not included in the sludge disposal system.

The available site for the treatment plant is between the West Branch Delaware River and Delaware Street. Access and service roads, transmission forcemain, lift station and site work are included in this preliminary layout.

To attain the immediate and future effluent quality objectives, treatment may be carried out by a combination of biological and chemical processes. If phosphate removal becomes a future requirement, it could be achieved by lime precipitation of the phosphate in the final settling and coagulation tank or by alum addition. Sludge produced in the final settling and coagulation tank is suitable for dewatering.

Until such time when phosphate removal is required, the plant will use only a limited quantity of lime for final coagulation. The provision of lime-feeding equipment storage bins and additional sludge dewatering system can be deferred until such time as phosphate removal is practiced.

The process units are designed for an average flow of 1.16 mgd with peak hourly flow of 3.78 mgd.

The screened influent will be pumped and metered to the primary settling tank influent distribution chamber and mixed with a recirculation flow from the 2nd stage packed tower. The combined flow will continue through the primary tanks. The effluent from the primary settling tanks is pumped up to the 1st stage packed tower distributor. This 1st stage effluent is pumped to the 2nd stage packed tower distributor, about 50% of the effluent of the 2nd stage packed tower will be returned as a recirculation flow to the influent distribution chamber of the primary settling tanks. The process flow stream continues through the final settling and coagulation tanks, chlorine contact tank and is finally diffused in the receiving waters of West Branch Delaware River.

Sludge from the primary and final settling tanks and coagulation tanks is pumped to sludge thickeners.

The sludge thickener underflow will be stored in a sludge storage tank prior to dewatering. The sludge cake will be disposed of in a sanitary landfill.

The treatment of whey-bearing waste and its sludge dewatering is associated with objectionable odors. Covers will be provided for the packed towers and odor control ventilation equipment would be provided.

Cost of Construction Program

The estimated 1971 (projected ENR index in Walton area: 1540) construction cost is based on constructing the plant by competitive contract methods. The estimates include an allowance for contingencies and engineering services.

A combined State and Federal grant (60%), as provided by Public Law 660, has also been assumed.

A summary of cost estimates for a complete waste water treatment facility and sewerage system is given in Table 5. Alternative No. 1 would collect and treat all domestic and industrial waste from Walton at a cost of about $5,806,000 while Alternative No. 2 would not accept certain industrial discharges, notably those from Breakstone; its cost would be about $3,645,000.

The predesign estimate of cost for Alternative No. 1 (all Walton wastes, including those from Breakstone) is $3,416,000 (Table 6). This amount represents a revision of the costs given in the May 1968 Feasibility Report. The new cost is based on the estimate for an entirely different process than that used as a model in the May 1968 study. Additionally, all estimates have been revised upward by 37% of the estimate given in May 1968. This rapid rate of increase reflects the continuing inflationary escalation in construction of waste treatment plants at a compounded rate of about 8% per year. Additionally, it is estimated that the Binghamton area leads the national construction cost average by about 10%.

The effect of sharing waste treatment and transmission costs with Breakstone and the State of New York under its Construction Grant Program is examined in Table 7 and Table 8.

TABLE 5

Summary of Alternative Capital Cost Estimates for Complete Wastewater Facility Including Engineering and Contingencies

(ENR Index = 1540)

	Description	Alternative No. 1	Alternative No. 2
1.	Treatment Plant	$2,749,000	$ 680,000
2.	Transmission System	667,000	575,000
3.	Initial Phase - Sewerage	406,000	406,000
4.	Subtotal - First Phase Construction	$3,822,000	$1,661,000
5.	Final Phase - Sewerage	1,984,000	1,984,000
6.	Total Capital Cost	$5,806,000	$3,645,000

TABLE 6

Estimated Cost of Treatment and Transmission Facilities Alternative No. 1 Including Breakstone Waste

(ENR Index = 1540)

I. Treatment Facilities	
1. Treatment Plant	$2,199,000
2. Engineering and Contingencies	550,000
3. Subtotal - Construction	$2,749,000
II. Transmission Units	
1. Force Main	$ 137,000
2. Pumping Stations	102,000
3. Interceptors	287,000
4. Rights-of-Way	8,000
5. Subtotal	$ 534,000
6. Engineering and Contingencies	133,000
7. Subtotal - Construction	$ 667,000
III. Treatment System	
1. Treatment Facilities	$2,749,000
2. Transmission Units	667,000
3. Total	$3,416,000

TABLE 7

Allocation of Capital Cost of Treatment Plant to Waste Loading Parameters Alternative No. 1 Including Breakstone Waste

Item and Description	Estimated Construction Cost (ENR=1540)	Allocation Among Parameters							
		Peak Flow		Average Flow		Dissolved BOD		Suspended Solids	
		Per-cent	Amount	Per-cent	Amount	Per-cent	Amount	Per-cent	Amount
I. Effluent Treatment Facilities									
Entrance Structure, Bar Screen, Comminutor	$ 58,000	100%	$ 58,000	-	-	-	-	-	-
Raw Sewage Pumping Station	63,000	100	63,000	-	-	-	-	-	-
Parshall Flume and Meter	7,000	-	-	100%	$ 7,000	-	-	-	-
Primary Settling Tanks	102,000	-	-	100	102,000	-	-	-	-
Trickling Filters	455,000	-	-	-	-	100%	$ 455,000	-	-
Trickling Filter Pumping Stations	128,000	100	128,000	-	-	-	-	-	-
Recirculation Control Box	18,000	-	-	-	-	100	18,000	-	-
Final Clarifiers	140,000	-	-	100	140,000	-	-	-	-
Chlorine Contact Tank	41,000	100	41,000	-	-	-	-	-	-
Yard Piping, Outfall and Diffuser	87,000	100	87,000	-	-	-	-	-	-
Chemical Feed Equipment and Storage	97,000	-	-	50	48,500	50	48,500	-	-
Nutrient Feed Equipment	21,000	-	-	-	-	100	21,000	-	-
Subtotal	$1,217,000	31.0%	$377,000	24.4%	$297,500	44.6%	$ 542,500	-	-

TABLE 7

(continued)

Item and Description	Estimated Construction Cost (ENR=1540)	Allocation Among Parameters							
		Peak Flow		Average Flow		Dissolved BOD		Suspended Solids	
		Per-cent	Amount	Per-cent	Amount	Per-cent	Amount	Per-cent	Amount
II. Sludge Disposal Facilities									
Sludge Pumping Station	$ 59,000								
Sludge Thickeners and Pump Station	98,000								
Sludge Dewatering Equipment and Building	425,000								
Sludge Storage Tank and Mixer	52,000								
Odor Control Equipment	115,000								
Subtotal	$ 749,000					.788%	$ 590,000	.212%	$159,000
Subtotal, Effluent and Sludge	$1,966,000	19.2%	$377,000	15.2%	$297,500	58.0%	$1,132,500	8.1%	$159,000
III. Pro Rata Items									
Administration Building	$ 64,000								
Emergency Power Generator	12,000								
Piles, Foundation and Dewatering	78,000								

TABLE 7

(continued)

	Estimated	Allocation Among Parameters							
	Construction	Peak Flow		Average Flow		Dissolved BOD		Suspended Solids	
Item and Description	Cost (ENR=1540)	Per-cent	Amount	Per-cent	Amount	Per-cent	Amount	Per-cent	Amount
III. Pro Rata Items (continued)									
Site Work and Access Road	$ 64,000								
Land	15,000								
Subtotal	$ 233,000	19.2%	$ 45,000	15.2%	$ 35,500	58.0%	$ 136,000	7.1%	$ 16,500
Total Treatment Plant	$2,199,000	19.2%	$422,000	15.2%	$333,000	58.0%	$1,268,500	7.6%	$175,500
Engineering and Contingencies @ 25%	550,000	19.2	106,000	15.2	84,000	58.0	320,000	7.6	40,000
Total Treatment Plant	$2,749,000	19.2%	$528,000	15.2%	$417,000	58.0%	$1,588,500	7.6%	$215,000
Loading Parameter Rate		3.78 mgd	$139,500/ mgd	1.16 mgd	$360,000/ mgd	5,860 #/day	$272/ #/day	1,580 #/day	$134/ #/day

Note: #/day = lbs/day.

TABLE 8

Treatment of Whey and Sewage
Allocation of Sludge Disposal Facilities' Capital Cost to BOD and Suspended Solids Loadings for 1990 Conditions

Source	Amount (Lbs/Day)	Relative Contribution
1. Raw Waste Solids	1,580	21.2%
2. BOD Solids		
a. Biological Sludge	3,900	
b. Precipitate	1,500	
c. Subtotal	5,400	78.8
3. Total Solids in System	6,980	100.0%
4. Composition of Solids Removed		
a. Raw Waste Source		21.2%
b. BOD Source		78.8
c. Total		100.0%

The division of capital cost between Breakstone and Walton is based upon their relative contributions of four major design loading parameters and a detailed allocation of the capital cost of each major treatment unit among the loading parameters.

Table 7 presents the allocation of treatment unit costs to loading parameter. The procedure assigns the cost of a unit to the design parameter(s) which determines the capacity of the particular unit operation. Allocation of the capital costs of sludge disposal facilities is made between suspended solids in the untreated waste and suspended solids generated from BOD removal. Solids generated from final clarifier coagulation are allocated to BOD. Table 8 presents the waste solids material balance data in terms of relative contribution from BOD and raw waste solids source.

Treatment plant items which cannot be attributed to a specific design loading, such as administration building, are prorated among the design loading parameters based on the allocations achieved for all other units. Cost allocations are also presented in terms of capital cost per unit amount of each design loading, i.e.:

$139,500 per mgd of peak hourly flow
360,000 per mgd of average daily flow
272 per lb per day of dissolved BOD
134 per lb per day of suspended solids

These unit capital costs may be used to estimate changes in total capital cost resulting from changes in design loadings.

Capital cost distribution between Breakstone and Walton, using the above rate structure, is summarized on Table 9. In the case of plant Alternative No. 1, the State's share of construction cost would be $2,050,000, Breakstone's share would be $814,250 and Walton's share would be $551,750. Without State participation, Breakstone's share would be $2,024,250 and Walton's share would be $1,391,750.

An independent municipal plant and transmission system would cost Walton about $1,255,000 without State participation and about $505,000 with State aid as shown in Table 10. Capital costs for an independent Walton treatment plant were obtained from a compilation of experience costs for various plant sizes as prepared by State and Federal agencies.

Operating Costs

Operating costs for Alternative No. 1 treatment facilities are estimated on Table 11. The predesign estimate is $127,000 per year without State aid and $85,000 per year with State aid.

The effect of sharing treatment plant operating costs among Breakstone, Walton and the State of New York is examined in Tables 12 through 14.

TABLE 9

Distribution of Capital Cost for Waste Treatment Alternative No. 1 Including Breakstone Waste

(ENR Index = 1540)

Loading Parameters

Q_m = Maximum Hourly Flow
Q_a = Average Daily Flow
BOD_D = Average Dissolved BOD
SS = Average Suspended Solids
PR = Pro Rata

Treatment Units	Parameter	Estimated Capital Costs	Distribution of Capital Costs			
			Breakstone		Walton	
			Percent	Amount	Percent	Amount
I. Waste Treatment Facilities						
Entrance Structure, Bar Screen and Comminutor	Q_m	$ 58,000	36.5%	$ 21,200	63.5%	$ 36,800
Raw Sewage Pumping Station	Q_m	63,000	36.5	23,000	63.5	40,000
Parshall Flume and Meter	Q_a	7,000	54.2	3,800	45.7	3,200
Primary Settling Tanks	Q_a	102,000	54.2	55,750	45.3	46,250
Trickling Filters	BOD_D	455,000	91.0	414,000	9.0	41,000
Trickling Filter Pumping Stations	Q_m	128,000	36.5	47,000	63.5	81,000
Recirculation Control Box and Equipment	BOD_D	18,000	91.0	16,400	9.0	1,600
Final Clarifiers	Q_a	140,000	54.2	76,200	45.6	63,800
Chlorine Contact Tank and Equipment	Q_m	41,000	36.5	15,000	63.2	26,000
Yard Piping, Plant Outfall and Diffuser	Q_m	87,000	36.5	31,750	63.5	55,250
Chemical Feed Equipment and Storage	Q_a&BOD_D	97,000	72.6	70,400	27.4	26,600
Nutrient Feeding Equipment	BOD_D	21,000	91.4	19,200	9.0	1,800
Subtotal, Waste Treatment Facilities		$1,217,000	65.6%	$ 793,700	34.4%	$ 423,300

TABLE 9

(continued)

Treatment Units	Parameter	Estimated Capital Costs	Distribution of Capital Costs: Breakstone Percent	Breakstone Amount	Walton Percent	Walton Amount
II. Sludge Disposal Facilities						
Sludge Pumping Station	BOD SS	$ 59,000	76.2%	$ 45,000	23.8%	$ 14,000
Sludge Thickeners and Pumping Station	BOD SS	98,000	76.2	75,000	23.8	23,000
Sludge Dewatering Equipment and Building	BOD SS	425,000	76.2	325,000	23.8	100,000
Sludge Storage Tank and Mixer	BOD SS	52,000	76.2	39,600	23.8	12,400
Odor Control Equipment	BOD SS	115,000	76.2	88,000	23.8	27,000
Subtotal, Sludge Disposal Facilities		$ 749,000	76.2%	$ 572,600	23.8%	$ 176,400
Subtotal, Items I and II		$1,966,000	69.5%	$1,366,300	29.5%	$ 599,700
III. Pro Rata Items						
Administration Building	PR	$ 64,000	69.5%	$ 44,500	29.5%	$ 19,500
Emergency Power Generator	PR	12,000	69.5	8,400	29.5	3,600
Sheet Piles, Foundation and Dewatering	PR	78,000	69.5	54,000	29.5	24,000
Site Work and Access Road	PR	64,000	69.5	44,500	29.5	19,500
Land	PR	15,000	69.5	10,450	29.5	4,550
Subtotal, Pro Rata Items		$ 233,000	69.5%	$ 161,850	29.5%	$ 71,150
IV. Total Treatment Plant						
Estimate as above		$2,199,000	69.5%	$1,527,850	29.5%	$ 671,150
Engineering and Contingencies		550,000	69.5	382,000	29.5	168,000
Total Estimated Cost		$2,749,000	69.5%	$1,909,850	29.5%	$ 839,150

TABLE 9

(continued)

Treatment Units	Parameter	Estimated Capital Costs	Distribution of Capital Costs			
			Breakstone		Walton	
			Percent	Amount	Percent	Amount
V. Transmission Units						
Force Main	Q_m	$ 137,000	36.5%	$ 50,000	63.5%	$ 87,000
Pumping Station	Q_m	102,000	0	0	100.0	102,000
Interceptors	Q_m	287,000	14.0	40,000	86.0	247,000
Subtotal	Q_m	$ 526,000	17.1%	$ 90,000	82.9%	$ 436,000
Rights of Way	PR	8,000	17.1	1,400	82.9	6,600
Subtotal	Q_m	$ 534,000	17.1%	$ 91,400	82.9%	$ 442,600
Engineering and Contingencies		133,000	17.1	23,000	82.9	110,000
Total Estimated Cost		$ 667,000	17.1%	$ 114,400	82.9%	$ 552,600
VI. Total System Cost						
Treatment Plant		$2,719,000	69.5%	$1,909,850	29.5%	$ 839,150
Transmission Units		667,000	17.1	114,400	82.9	552,600
Total System		$3,416,000	59.0%	$2,024,250	41.0%	$1,391,750
VII. Net System Cost						
Total Estimated		$3,416,000	59.0%	$2,024,250	41.0%	$1,391,750
State Grant		2,050,000	59.0	1,210,000	41.0	840,000
Net Cost		$1,366,000	59.0%	$ 814,250	41.0%	$ 551,750

TABLE 10

Estimated Capital Cost of Treatment and Transmission Facility
Alternative No. 2 Without Breakstone Waste

(ENR Index = 1540)

		Cost
I.	Treatment Facilities	
	1. Treatment Plant	$ 530,000
	2. Land	15,000
	3. Subtotal - Construction	$ 545,000
	4. Engineering and Contingencies	135,000
	5. Total	$ 680,000
II.	Transmission Units	
	1. Force Main	$ 110,000
	2. Pumping Stations	68,000
	3. Interceptors	274,000
	4. Rights-of-Way	8,000
	5. Subtotal - Construction	$ 460,000
	6. Engineering and Contingencies	115,000
	7. Total	$ 575,000
III.	Treatment System	
	1. Treatment Facilities	$ 680,000
	2. Transmission Units	575,000
	3. Subtotal - Treatment System	$1,255,000
	4. State Aid	750,000
	5. Net Cost	$ 505,000

TABLE 11

Treatment of Whey and Sewage
Estimated Treatment Plant Operating Costs - Alternative No. 1
Initial Condition

Description		Annual Cost
1.	Labor	
	a. Sludge Disposal	$ 20,000
	b. General Operating	20,000
	c. Total	$ 40,000
2.	Chemicals	19,000
3.	Process Power	9,500
4.	Maintenance	28,000
5.	Miscellaneous General Power and Fuel	9,500
6.	Subtotal	$106,000
7.	Contingencies @ 20%	21,000
8.	Total	$127,000
9.	State Aid	42,000
10.	Net Operating Cost	$ 85,000

TABLE 12

Annual Contributions of Loadings
Initial Conditions - Alternative No. 1

Characteristic	Annual Amount	Percentage
1. Flow - mg		
a. Breakstone	240.0	83.2%
b. Walton	47.5	16.8
c. Total	287.5	100.0%
2. Dissolved BOD - lbs		
a. Breakstone	930,000	96.5%
b. Walton	33,000	3.5
c. Total	963,000	100.0%
3. Suspended Solids - lbs		
a. Breakstone	385,000	80.0%
b. Walton	95,000	20.0%
c. Total	480,000	100.0%

TABLE 13

Allocation of Operating Cost of Treatment Plant to Waste Loading Parameters
Alternative No. 1 Including Breakstone Waste

Operating Cost	Annual Amount	Allocation to Loading					
		Flow		BOD		Suspended Solids	
		Percent	Amount	Percent	Amount	Percent	Amount
1. Labor							
a. Sludge Disposal	$ 20,000	-		78.8%	$15,750	21.2%	$ 4,250
b. General Operation	20,000	100.0%	$20,000	-	-	-	-
c. Total	$ 40,000	50.0%	$20,000	39.5%	$15,750	10.6%	$ 4,250
2. Chemical	19,000	13.2	2,500	76.0	14,400	10.8	2,100
3. Process Power	9,500	58.0	5,500	33.0	3,150	9.0	850
4. Maintenance	28,000	44.0	12.400	45.0	12,600	11.0	3,000
5. Subtotal	$ 96,500	42.0%	$40,400	47.5%	$45,900	10.5%	$10,200
6. Miscellaneous, General Power, Fuel	9,500	42.0	4,000	47.5	4,500	10.5	1,000
7. Subtotal	$106,000	42.0%	$44,400	47.5%	$50,400	10.5%	$11,200
8. Contingencies @ 20%	21,000	42.0	8,800	47.5	10,000	10.5	2,200
9. Total	$127,000	42.0%	$53,200	47.5%	$60,400	10.5%	$13,400

TABLE 14

Distribution of Operation and Maintenance Costs for Waste Treatment Alternative No. 1 Including Breakstone Waste

Operation and Maintenance	Estimated Amount	Distribution of Annual Cost			
		Breakstone		Walton	
		Percent	Amount	Percent	Amount
1. Labor					
a. Sludge Disposal	$ 20,000	93.0%	$ 18,600	7.0%	$ 1,400
b. General Operating	20,000	83.8	16,700	16.2	3,300
c. Subtotal	$ 40,000	88.0%	$ 35,300	11.0%	$ 4,700
2. Chemicals	19,000	93.5	17,700	6.5	1,300
3. Process Power	9,500	87.0	8,300	13.0	1,200
4. Maintenance	28,000	90.5	25,300	9.5	2,700
5. Miscellaneous Power and Fuel	9,500	89.5	8,500	10.5	1,000
6. Subtotal	$106,000	90.0%	$ 95,100	10.0%	$10,900
7. Contingencies @ 20%	21,000	90.0	18,900	10.0	2,100
8. Total	$127,000	90.0%	$114,000	10.0%	$13,000
9. Less State Aid	42,000	90.0	37,800	10.0	4,200
10. Net	$ 85,000	90.0%	$ 76,200	10.0%	$ 8,800

The division of costs between Breakstone and Walton is based upon their respective contribution to the annual amounts of flow, BOD and suspended solids contributed to the treatment plant.

Table 12 presents the summary of annual contribution anticipated for the initial year of operation.

Table 13 presents the allocation of treatment operating costs to loading parameters. The procedure assigns the cost of operation to the parameter(s) which determines either the capacity of a particular treatment unit or the need for operating attention. Maintenance is estimated at 5% per year based upon estimated purchase price of mechanical equipment. Miscellaneous items are prorated based upon allocation achieved for other operating items.

Operating cost distribution between Breakstone and Walton using the relative contributions from Table 12 and the allocations presented in Table 13 are summarized on Table 14. For Alternative No. 1, Breakstone's share of operating costs is estimated at $114,000 per year without State aid, and $76,200 per year with State aid. Walton's share without State aid is estimated at $13,000 per year and at $8,800 per year with State aid.

Operating costs for Alternative No. 2 (excluding Breakstone) are estimated at $75,000 per year for the initial year of operation. The estimate is based upon a compilation of average operating cost experience data compiled by State aid and Federal agencies.

Total Annual Cost Comparison

Total annual costs for Walton treatment and transmission system for Alternative Nos. 1 and 2 are compared on Table 15. As shown in the tabulation, a joint Breakstone-Walton treatment and transmission would reduce Walton total annual cost by 30% to 40% when compared with an independent alternative. Excluding State aid, Walton's total annual costs for treatment and transmission are reduced from $169,000 per year to $117,500 per year. Including State aid, Walton's total annual costs for treatment and transmission are reduced from $87,500 per year to $50,300 per year. An effective rate of interest of 7% per year has been assumed for Walton municipal bonds in view of the persistently high cost of money evidenced in the municipal bond market.

TABLE 15

Total Annual Cost Comparison
Treatment and Transmission Facilities
Walton Sewage

Annual Cost	Estimated Annual Walton Cost Alternative No. 1	 Alternative No. 2
1. Interest and Amortization*		
a. Treatment Plant	$ 63,000	$ 51,000
b. Transmission Facilities	41,500	43,000
c. Subtotal - Construction	$104,500	$ 94,000
2. Operation of Treatment Plant	13,000	75,000
3. Total Annual Cost	$117,500	$169,000
4. State Aid		
a. Construction	$ 63,000	$ 56,500
b. Operation	4,200	25,000
c. Total	$ 67,200	$ 81,500
5. Net Total Annual Cost	$ 50,300	$ 87,500

*40 years at 7%.

System Costs to Walton

Components of a complete system for Walton comprise the following:

1. Initial phases of sewerage system
2. Treatment plant and transmission facilities
3. Final phases of sewerage system

Table 16 presents estimated capital costs for the first phase sewerage system construction. Treatment and transmission capital cost under Alternative No. 1 have already been presented on Table 5. Table 17 presents estimated capital costs for the final phase of the sewerage system.

Table 18 examines the capital cost to Walton for a complete system under Alternative No. 1, incorporating all financial aid Walton is qualified to receive, ignoring the problem of availability of funds. Walton's share of capital costs would be about $1,739,250 for a complete system. The capital cost of the initial phase of construction of sewers, treatment and transmission facilities would be about $755,000.

Operating costs to Walton for treatment and transmission under Alternative No. 1 are presented on Table 19. Operating costs for sewerage system needs are shown on Table 14.

Table 20 examines total annual costs under Alternative No. 1. Incorporating all financial aid Walton is qualified to receive, Walton's share of total annual costs for treatment, transmission and first stage sewerage construction is estimated at $72,800 per year or about $66/year/connection (assuming 1,100 connections). Of this amount, treatment and transmission account for some $50,000 per year or $45.5/year/connection.

In terms of tax rates, treatment, transmission and first stage sewerage construction would be equivalent to $18/$1,000 of assessed valuation. Of this amount, treatment and transmission account for some $12.40/$1,000 of assessed valuation.

TABLE 16

Estimated Cost of Initial Phase of Walton Sewerage System

(ENR Index = 1540)

Initial Phase			
1.	Sewer-in-Place	13,500 LF	$ 260,000
2.	Manholes	50	27,000
3.	House Connections	220	48,000
4.	Subtotal - Construction		$ 335,000
5.	Engineering and Contingencies		71,000
6.	Total - Initial Phase		$ 406,000

TABLE 17

Estimated Cost of Final Phase of Walton Sewerage System

(ENR Index = 1540)

Complete Sewer System			
1.	Sewer-in-Place	72,400 LF	$1,280,000
2.	Manholes	240	128,000
3.	House Connections	1,100	230,000
4.	Subtotal - Construction		$1,638,000
5.	Engineering and Contingencies		330,000
6.	Total - Final Phase		$1,968,000

TABLE 18

Capital Cost to Walton for Complete System
Alternative No. 1

(ENR Index = 1540)

Description	Estimated Amount	Grants and Shares	Net Amount
1. Treatment Plant		$1,650,000* 765,000**	
	$2,749,000	$2,415,000	$ 334,000
2. Transmission System		$ 400,000* 49,250**	
	$ 667,000	$ 449,250	$ 217,750
3. Sewer System			
a. Initial Phase	$ 406,000	$ 203,000***	$ 203,000
b. Final Phase	1,968,000	984,000***	984,000
c. Subtotal - Sewerage	$2,374,000	$1,187,000	$1,187,000
4. First Phase Construction			
a. Treatment Plant	$2,749,000	$2,415,000	$ 334,000
b. Transmission System	667,000	449,250	217,750
c. Initial Phase Sewage	406,000	203,000	203,000
d. Total - First Phase	$3,822,000	$3,067,250	$ 754,750
5. Complete Construction			
a. First Phase Construction	$3,822,000	$3,067,250	$ 754,750
b. Final Phase Sewerage	1,968,000	984,000	984,000
c. Total - All Phases	$5,790,000	$4,051,250	$1,738,750

*State grant of 60% of cost.

**Breakstone share.

***FHA grant of 50% of cost.

TABLE 19

Estimate of Operating Cost of Walton Sewerage System

(ENR Index = 1540)

Description	Annual Amount
I. Initial Phase of Sewerage System	
1. Maintenance	$ 2,100
2. Wages	3,100
3. Miscellaneous Expenses	2,100
4. Subtotal - Initial Phase	$ 7,300
II. Final Phase of Sewerage System	
1. Maintenance	$ 4,800
2. Wages	7,200
3. Miscellaneous Expenses	4,800
4. Subtotal - Final Phase	$16,800
III. Total - Sewerage System	$24,100

TABLE 20

Total Annual Cost to Walton for Complete System
Alternative No. 1

Description	Estimated Amount	Aid Amount	Net Amount
1. Interest and Amortization*			
a. Treatment	$ 63,000	$ 38,000**	$ 25,000
b. Transmission	41,500	25,000**	16,500
c. Sewerage System Initial Phase	30,500	15,250***	15,250
d. Subtotal	$135,000	$ 78,250	$ 56,750
e. Sewerage System Final Phase	149,000	74,500***	74,500
f. Total	$284,000	$152,750	$131,250
2. Operation and Maintenance			
a. Treatment	$ 13,000	$ 4,200****	$ 8,800
b. Sewerage System Initial Phase	7,300	-	7,300
c. Subtotal	$ 20,300	$ 4,200	$ 16,100
d. Sewerage System Final Phase	16,800	-	16,800
e. Total	$ 37,100	$ 4,200	$ 32,900
3. Total Annual Cost			
a. Treatment, Transmission and Initial Sewerage System	$155,300	$ 82,450	$ 72,850
b. Final Sewerage Phase	165,800	74,500	91,300
c. Total	$321,100	$156,950	$164,150
	Say	$157,000	

*40-year bond @ 7%/year.

**State grant of 60% of cost.

***FHA grant of 50% of cost.

****State grant of 33% of cost.

Computer Program for Trickling Filter Process Designs

Program Description

The purpose of the program is the preparation of a preliminary design for packed tower trickling filters utilizing a number of alternative models. The models include: first order, and a retardant formulation.

The program consists of two elements, i.e., a main program and a subroutine. The file name is TPQ. The two elements (main program and a subroutine) are called TEST1 and TEST2, respectively. The program also consists of a data file called DATA.

Process possibilities include the following:

1. A single-stage process with the possibility of from one to four filters in parallel.
2. A two-stage process (two filters in series) with the possibility of from one to four filters in parallel.
3. A three-stage process (three filters in series) with the possibility of from one to four filters in parallel.

Units are sized assuming all of the above possibilities. The Appendix contains a sample printout of the program.

Description of Input

First Line:

(a) The number of kinetic routines you want to use (i.e., a number from 1 to 5).

(b) An identification number for each routine that is to be used according to the following scheme:

1 = First order
2 = Simple retardant
3 = Zero order
4 = Michaelis Menton
5 = Concentration dependent

Models 3 to 5 are for future development.

Second Line:

(a) The total overall efficiency required. It is read in as a decimal.

(b) The minimum application rate required for the filter media. It is expressed in the following units (gpm/SF).

Third Line:

(a) First filter height selected (ft)

(b) Second filter height selected (ft)

Fourth Line:

Characteristics of First Kinetic Routine Chosen

(a) BOD removal rate constant at 20°C

(b) "n" value of the media chosen

(c) Lbs/day of raw BOD entering the filter

(d) Actual temperature in °C

(e) Raw waste flow in gpm

(f) Temperature correction factor θ

Fifth Line:

Characteristics of Second Kinetic Routine Chosen

(a) BOD removal rate constant at 20°C

(b) "n" value of the media chosen

(c) Lbs/day of raw BOD entering the filter

(d) Actual temperature in °C

(e) Raw waste flow in gpm

(f) Temperature correction factor θ

Sixth Line to Eignth Line:

Same variables as lines four and five but for the third to the fifth kinetic routines. Models 3 to 5 are for future development and thus lines 6, 7, 8 are omitted at the present time.

All the data are input in free format separated by commas. The first line is inferred with no decimal points. All the remaining lines must have numbers with an expressed decimal point.

Numerical Example of Input

Assume two kinetic models, simple retardant first and first order. Next,

95% efficiency

1 gal./SF minimum application rate

Height No. 1 = 21 ft

Height No. 2 = 42 feet

First Order:

K20 = .03 gpm/CF

n = 1

W = 1,800 BOD lbs/day

Temperature = 22°C

Q = 694.4 gpm

θ = 1.035

Simple Retardant:

K20 = .03 gpm/CF

n = 1

W = 1,800 BOD lbs/day

Temperature = 22°C

Q = 694.4 gpm

θ = 1.035

Actual input would appear as follows:

```
2, 2, 1

.95, 1.
21., 42.
.03, 1., 1800., 22., 694.4, 1.035

.03, 1., 1800., 22., 694.4, 1.035
```

Actual Output

The output is neatly arranged and divided into the following sections.

Section 1 General Design Criteria

This section lists the variables which were input to the program and calculates the actual rate constant $K_T = K_{20} \cdot \theta^{t-20}$.

The following parameters are printed out:

1 BOD removal rate at 20°C
2 Actual temperature
3 Temperature correction factor
4 Actual BOD removal rate
5 Flow
6 BOD
7 Minimum application rate
8 Depth of tower
9 Total efficiency

Section 2 Design Criteria Including Branches 1, 2, 3 and 4

Branch 1

This branch prints out a table assuming that you have either a 1 stage, 2 stage or 3 stage process. This first table assumes that the flow recirculation ratio is zero. Recirculation is set at zero in this table in order to provide a record of:

(a) The need to provide for recirculation and, therefore, added tower volume, within any stage to insure achievement of a selected minimum application rate and

(b) The need to provide for additional stages to insure achievement of minimum application rates without using recirculation on each stage or

(c) Both of the above.

The parameters printed out are:

1 Efficiency per stage
2 Application rate per stage (gpm/SF)
3 Recirculation ratio per stage
4 Volume of media per stage (CF)
5 Stage volume divided by raw flow (CF/gpm)
6 Total volume of media (CF)
7 Flow pumped per stage (gpm)
8 Total flow pumped (gpm)
9 Number of pumping stations required

Branch 2

This branch prints out the organic loadings to each stage assuming either a 1, 2, or 3 stage process. For each stage a nominal diameter is calculated from one to four filters per stage.

Branches 3 and 4

These branches are the same as 1 and 2 respectively except that recirculation is added if required to make the application rate equal to the minimum allowable.

This output is repeated for each kinetic model desired. The program was written using Fortran V. The system used was a Univac 1108 Executive VIII computer.

SECTION V

CONSTRUCTION

Construction was limited to the installation of concrete foundation slab for acceptance of a packed tower field pilot plant. Photographs of the unit appear in Figure 24. A diagram of the unit is shown in Figure 25.

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SECTION VI

EXPERIMENTAL

Laboratory Phase

Sewage and industrial waste discharges are subject to pronounced hourly variations in flow, strength and characteristics. Under such unsteady conditions, the challenge associated with the field evaluation of the role of specific variables on process performance becomes greatly magnified. The evaluation of parameters is most effectively executed under carefully controlled laboratory conditions enabling isolation of the effects of specific variables. In addition, the laboratory approach enabled the investigation of a whey-sewage mixture prior to the provision of community sewage collection. The present investigation employed laboratory techniques for parameter evaluation except where practical considerations as to scale dictated field studies. The evaluation of sludge dewatering characteristics was the principal area in which scale requirements dictated field studies.

Methods and Materials

A synthetic waste substrate was formulated for use in all laboratory studies. The waste substrate was prepared from Breakstone whey, settled sewage from the city of Yonkers, New York, skim milk and tap water in accord with the following formula.

Whey	1.55%
Skim Milk	0.09
Settled Sewage	15.90
Tap Water	82.40
	99.94%

The formula is a simulation of the waste mixture expected at a Walton-Breakstone joint treatment plant. Representative values of the COD, BOD and suspended solids for the synthetic waste were 900, 650 and 100 ppm, respectively.

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The simulated waste was fed to four laboratory test stand units designed to simulate trickling filter performance kinetics. The test stand units, illustrated in Figures 7 and 8, were rectangular plane surfaces set at a specific incline. The filter lengths were side channeled to provide a controlled surface area of slime. The test stand units were constructed to provide flexibility in waste loading variation and system operation. Daily feed volumes were small enough to allow the entire filter effluent to be stored in a refrigerator for preservation during feeding and collection. Slime surfaces were sufficiently large to enable the investigation of a wide range of BOD removal efficiencies.

Plane recirculation ratios, as well as BOD and hydraulic loadings, were scaled to approximate prototype conditions. Application of feed and recycle was continuous with automatic temperature control. Operating characteristics are presented on Table 21. A period of 24 hours was allowed for development of steady state conditions between runs.

TABLE 21

Laboratory Trickling Filter Plane
Operating Characteristics

Characteristics	Laboratory Trickling Filter
1. Number of Units Run	4
2. Total Length (ft)	9 and 18
3. Available Media (SF)	.375 and .75
4. Volume of Feed Required per Day (1)	3 - 22
5. Temperature	Automatic Control ± 2°C
6. Sampling Procedure	Manual Grab Samples
7. Duration of Runs	3 to 5 days
8. Operation Schedule	7 days/week
9. Method of Operation	
a. Feed	Continuous
b. Recycle	Continuous

FIGURE 7

TYPICAL LABORATORY SIMULATED
TRICKLING FILTER PLANE

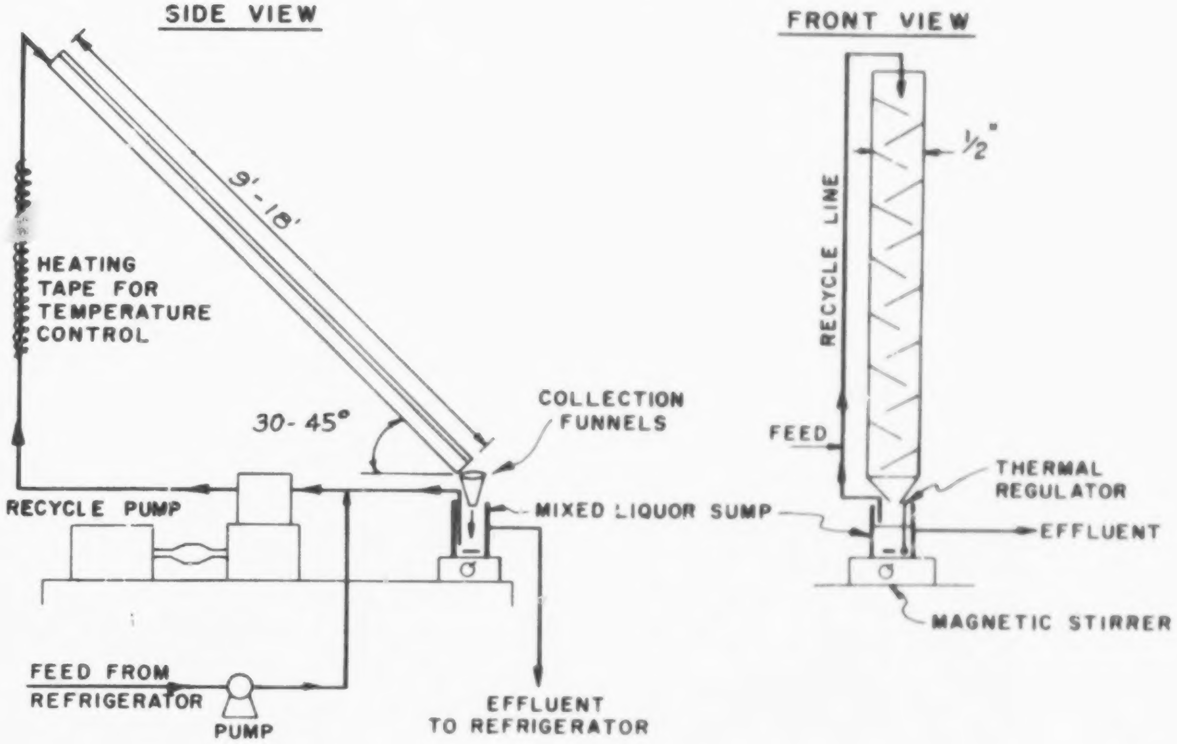
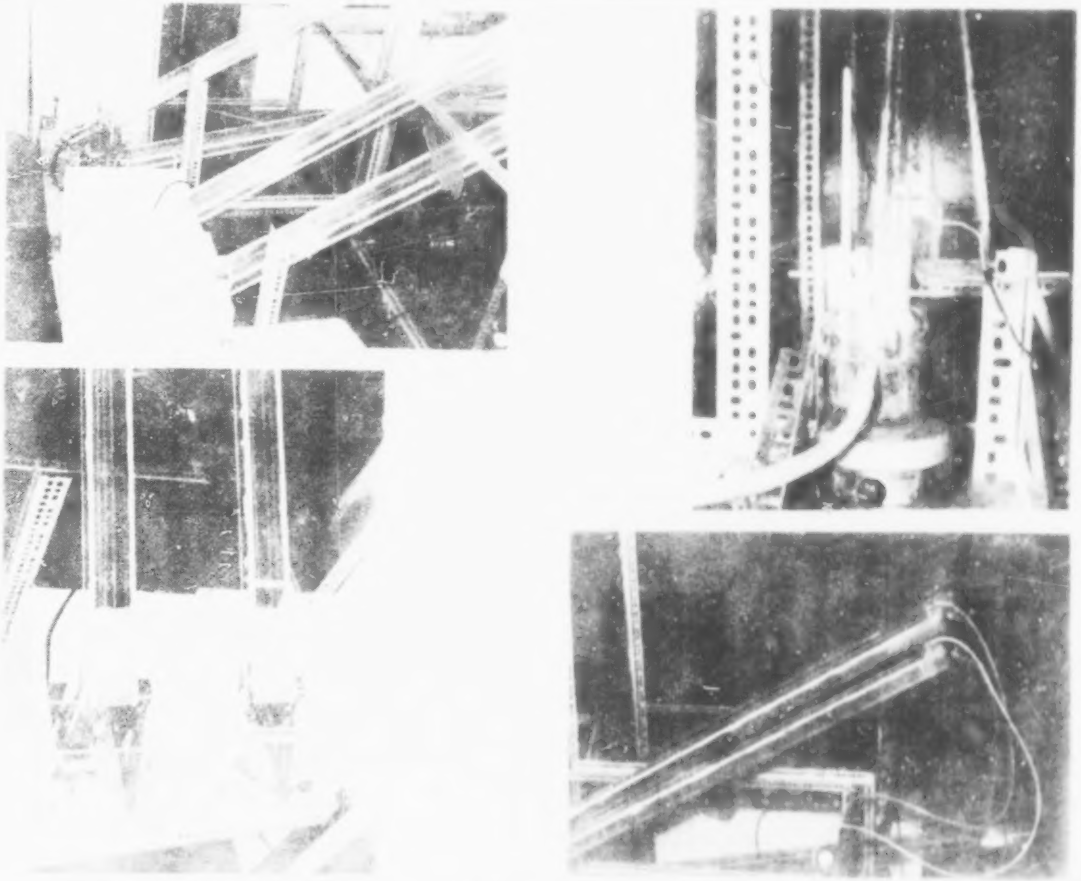

SIDE VIEW
9'-18'
HEATING
TAPE FOR
TEMPERATURE
CONTROL
30-45°
COLLECTION
FUNNELS
RECYCLE PUMP
MIXED LIQUOR SUMP
FEED FROM
REFRIGERATOR
PUMP
EFFLUENT
TO REFRIGERATOR
FRONT VIEW
½"
RECYCLE LINE
FEED
THERMAL
REGULATOR
EFFLUENT
MAGNETIC STIRRER

FIGURE 8



FILTER PLANE TEST STAND UNITS

Analysis of the simulated waste indicated a filtered BOD of approximately 600 mg/l. A nitrogen requirement of 5 lbs nitrogen per 100 lbs of BOD or 30 mg N/l was indicated for the whey-sewage waste. Analysis of grab samples of the simulated waste indicated the following nitrogen content.

Nitrogen Form	Nitrogen Concentration (mg-N/l)	TSS (mg/l)
Ammonia	.75	
Organic	6.0	100
Nitrate	.7	

Assuming all the nitrogen forms are available as nutrients, a nitrogen deficit of approximately 22.5 mg N/l exists. Nitrogen supplementation in the form of ammonium hydroxide was selected. A dosage of 37.5 mg N/l was selected to insure that nitrogen would not become limiting.

Representative effluent nitrogen concentrations for 75% removal of soluble BOD were:

Ammonia	20 mg N/l
Nitrate Nitrogen	1.5 mg N/l

Organic nitrogen varied depending upon the effluent suspended solids.

To prevent odorous nuisance conditions developing in the laboratories, the trickling filter planes were enclosed in plexiglass and facilities provided to deodorize the effluent air stream. A minimum air flow of 40 CF/gal. was provided. Total air flow over the four trickling planes averaged 40 CF/hr. A Welsbach Model T-816 laboratory ozonator was chosen as the ozone source. Its rated capacity of 8 gms ozone per hr using air as the feed gas insured adequate capacity over and above the 10 ppm dosage recommended by the manufacturer for deodorizing sewage sludges. Control of ozonation was accomplished using a Welsbach Model H-81 ozone meter. A minimum reactor detention time of 5 minutes was provided before exhausting the deodorized air effluent outside the laboratory.

Transient Response

In the investigation of biological systems it is necessary to manipulate variables affecting the system in a carefully controlled manner. A change in an input variable will cause the system to exhibit a transient and a steady-state response. Since kinetic formulations deal with steady-state responses, it was essential in the experimental design of the present study to allow time for dissipation of transient response prior to data collection.

The results presented in Figure 9 pertain to system response to 9 to 1 step-down and 9 to 1 step-up in organic loading inputs. The response to the step-down input required 22 hrs to reach steady state. The response to the step-up input required 6 hrs to reach steady state. The implication was that it would be feasible to collect data for parameter evaluation at intervals of 24 hrs following adjustment of variables.

Effect of Nutrients

A series of experiments was made to determine the effect of nutrient supplementation upon BOD removal performance. The nutrients selected for investigation were combinations of ferrous iron and ammonia. Data analysis indicated that the results fell within two groups. The data, presented as Figure 10, consisted of results obtained with no addition of nutrients and with the addition of ferrous iron only. The value of k'_{20} for this group ranged from 1.1 to 1.15 x 10^{-3} gpm/SF.

The second data group consisted of results obtained with addition of nutrient ammonia-nitrogen and with the addition of nutrient ammonia-nitrogen, plus ferrous iron. These results, given in Figure 11, yielded a value of k'_{20} of 1.6 x 10^{-3} gpm/SF. Thus, the addition of 1.5 ppm of ferrous iron had no effect on BOD removal, whereas the addition of 37.5 ppm of ammonia-nitrogen effected a 40% increase in the rate coefficient for BOD removal. The linearity exhibited by the plots supported the applicability of the formulation.

Effect of BOD Concentration

By grouping the data into high concentration and low concentration populations, it was possible to examine the effect of concentration on applicability of the proposed kinetic formulation. Such an analysis is presented as Figure 12, where the value of the BOD removal coefficient, k'_{20}, was 1.75 x 10^{-3} gpm/SF for both high and low concentration populations. It was concluded that within the range of experimentation, the proposed model described variations in BOD concentration of the waste.

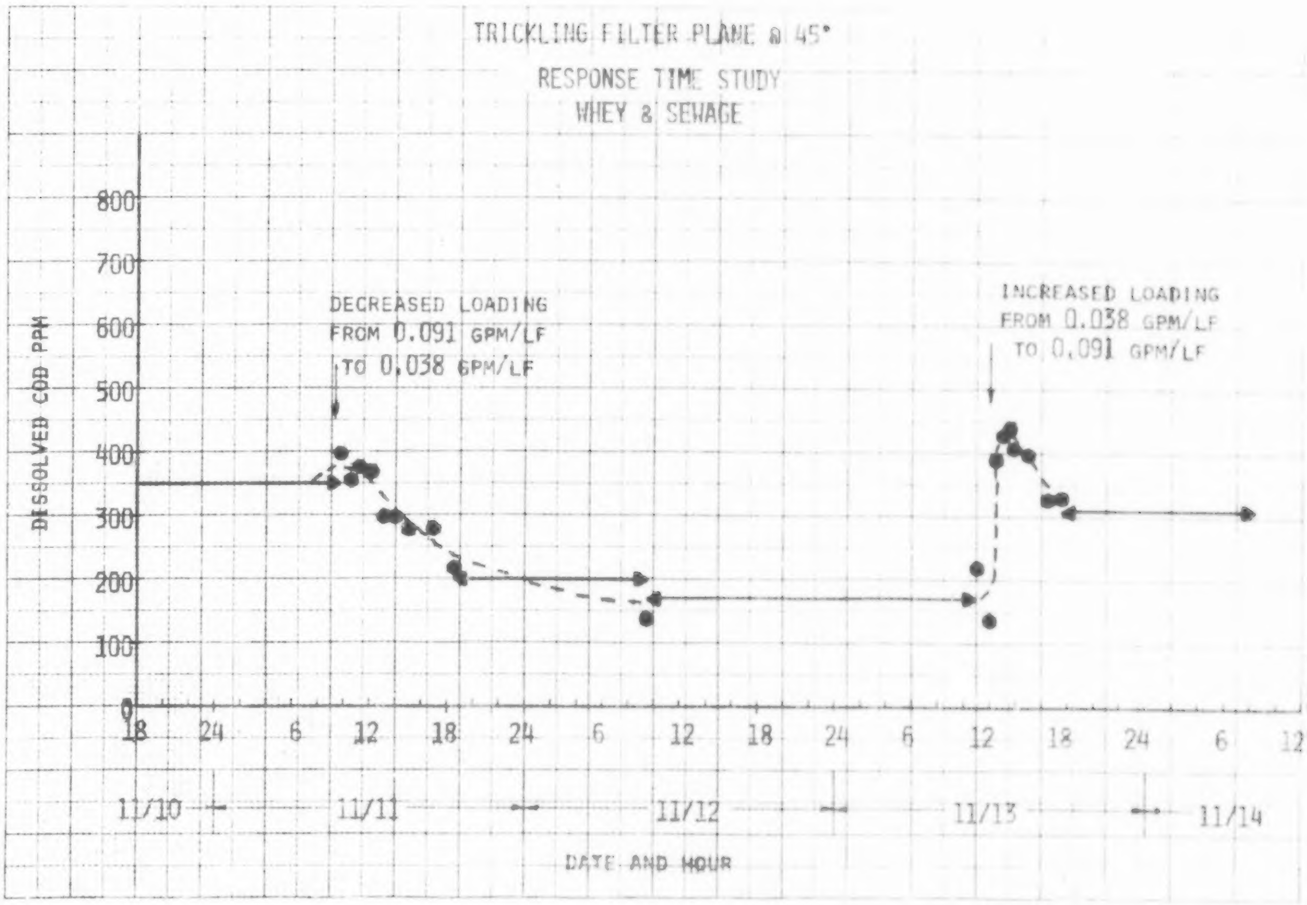


FIGURE 9

TRICKLING FILTER PLANE @ 45°
RESPONSE TIME STUDY
WHEY & SEWAGE

FIGURE 10

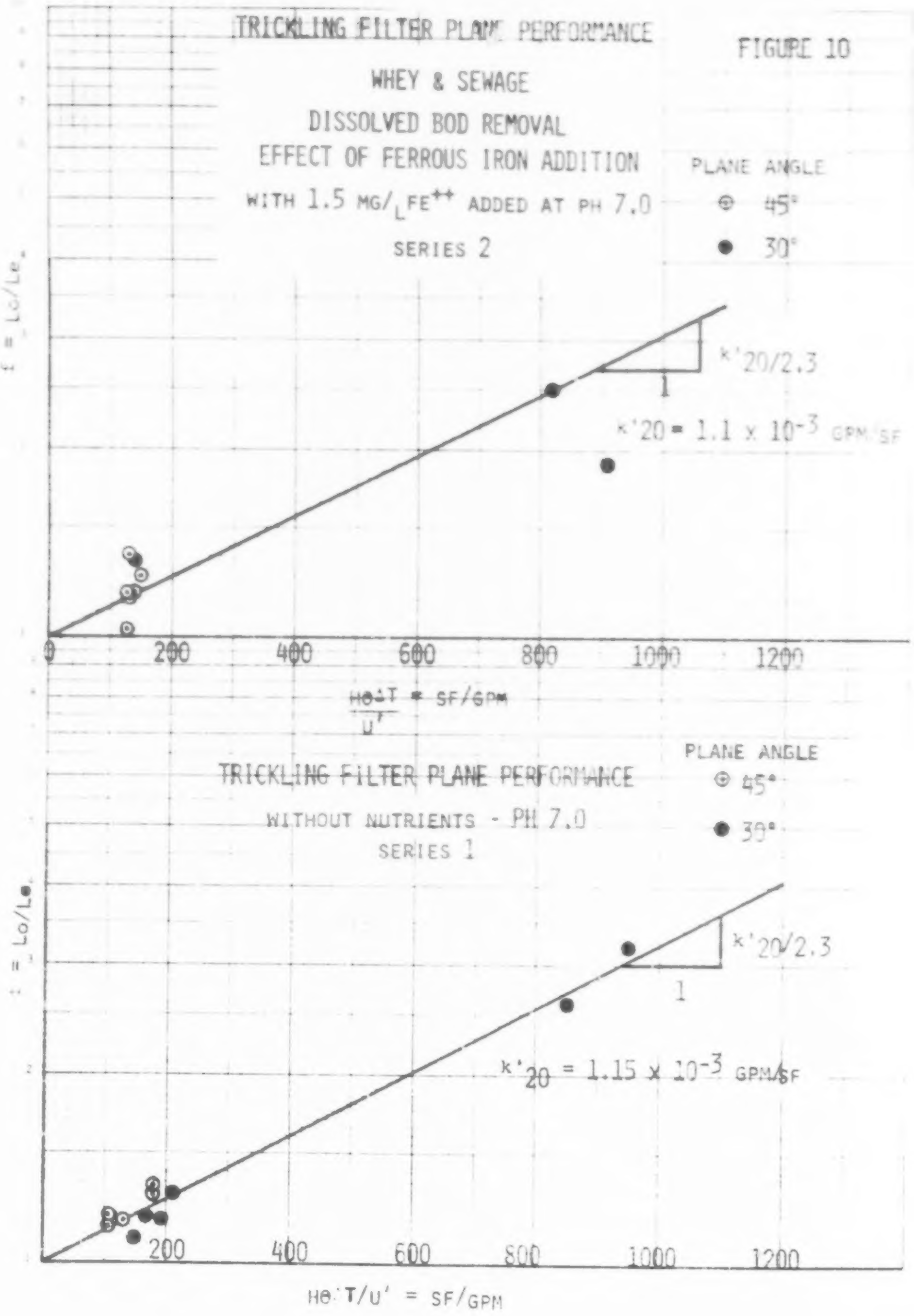
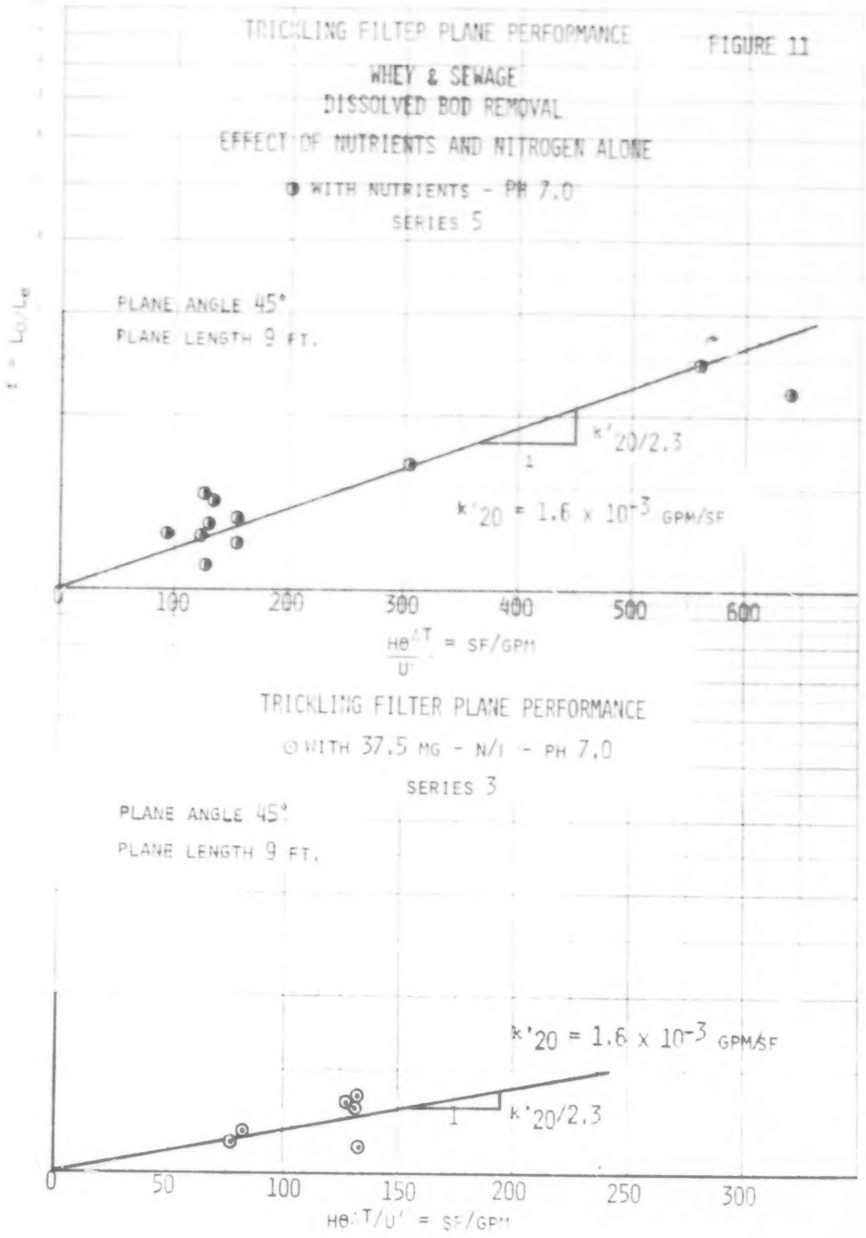

TRICKLING FILTER PLANE PERFORMANCE
WHEY & SEWAGE
DISSOLVED BOD REMOVAL
EFFECT OF FERROUS IRON ADDITION
WITH 1.5 MG/L FE++ ADDED AT PH 7.0
SERIES 2
PLANE ANGLE
⊕ 45°
● 30°
k'20/2.3
1
k'20 = 1.1 x 10-3 GPM/SF
f = Lo/Le
0
200
400
600
800
1000
1200
Hθ T/U' = SF/GPM
TRICKLING FILTER PLANE PERFORMANCE
WITHOUT NUTRIENTS - PH 7.0
SERIES 1
PLANE ANGLE
⊕ 45°
● 30°
k'20/2.3
1
k'20 = 1.15 x 10-3 GPM/SF
f = Lo/Le
200
400
600
800
1000
1200
Hθ T/U' = SF/GPM

FIGURE 11



TRICKLING FILTER PLANE PERFORMANCE

WHEY & SEWAGE
DISSOLVED BOD REMOVAL
EFFECT OF NUTRIENTS AND NITROGEN ALONE

● WITH NUTRIENTS - PH 7.0
SERIES 5

TRICKLING FILTER PLANE PERFORMANCE
⊙ WITH 37.5 MG - N/l - PH 7.0
SERIES 3

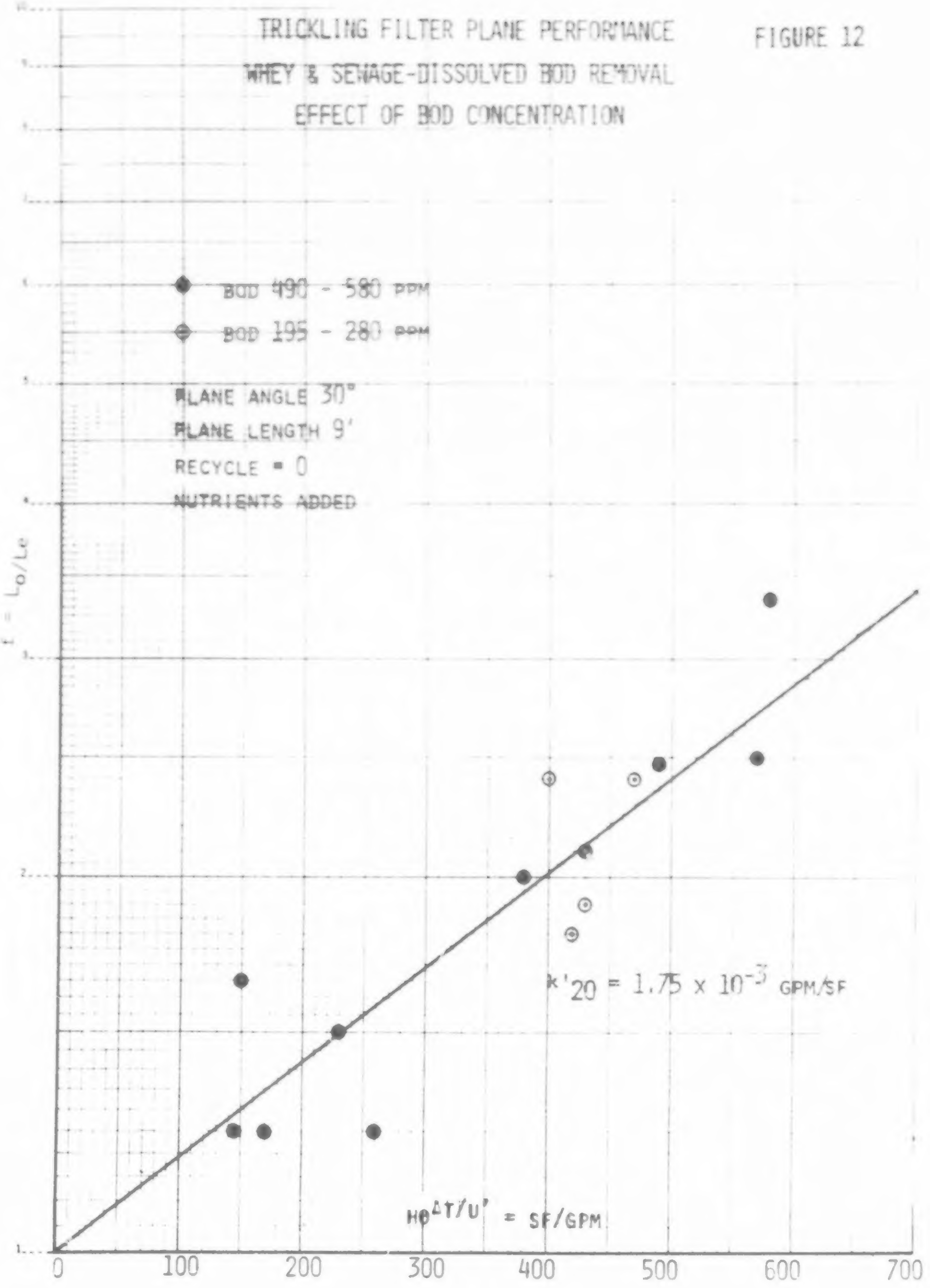


FIGURE 12

TRICKLING FILTER PLANE PERFORMANCE
WHEY & SEWAGE-DISSOLVED BOD REMOVAL
EFFECT OF BOD CONCENTRATION

Effect of Recycle

There is considerable controversy among researchers as to the effects of recycle on the performance of biological filters. By grouping the data of the present study into populations with recycle and without recycle, it was possible to obtain the analysis presented as Figure 13. With a recycle ratio of from 2 to 3, the rate coefficient for BOD removal, k'_{20}, was determined as 2.0×10^{-3} gpm/SF. The difference in indicated rate constant is considered within the spread of experimental data and it is concluded that, in accordance with theory, recirculation does not materially affect the value of BOD removal rate constant but must be included in the determination of hydraulic loading.

Effect of pH

The level of pH influences enzyme activity and culture characteristics in biological systems. The results of a limited number of data collection runs at different levels of influent pH are given in Figure 14. Examination of the results indicated a trend towards improved BOD removal rate at pH 7 or below. Data are sufficient only to show a trend toward pH effects. It is noted that similar trends were obtained by Wasserman [1] and Adamse [4] with other biological systems using whey as substrate.

Effect of Temperature

The performance of biological filters is affected by seasonal and waste temperature changes. The proposed kinetic formulation accounts for temperature effects by adjustment of the value of the BOD removal coefficient, k', in the following manner.

$$k'_t = k'_{20}\ \theta^{(t-20)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (\#36)$$

where:

k'_t = BOD removal rate coefficient at T°C

k'_{20} = BOD removal rate coefficient at 20°C

θ = constant

t = waste temperature, C°

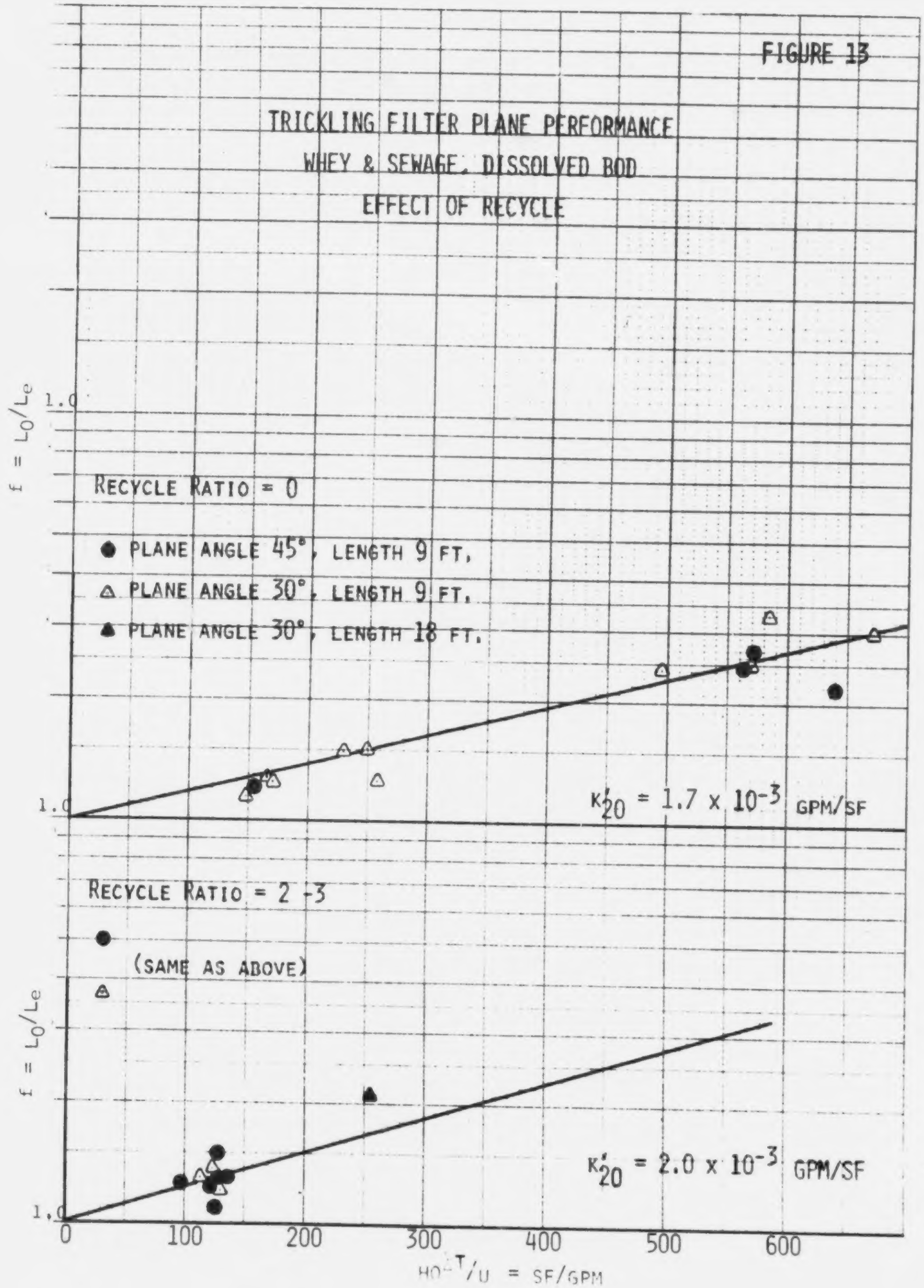
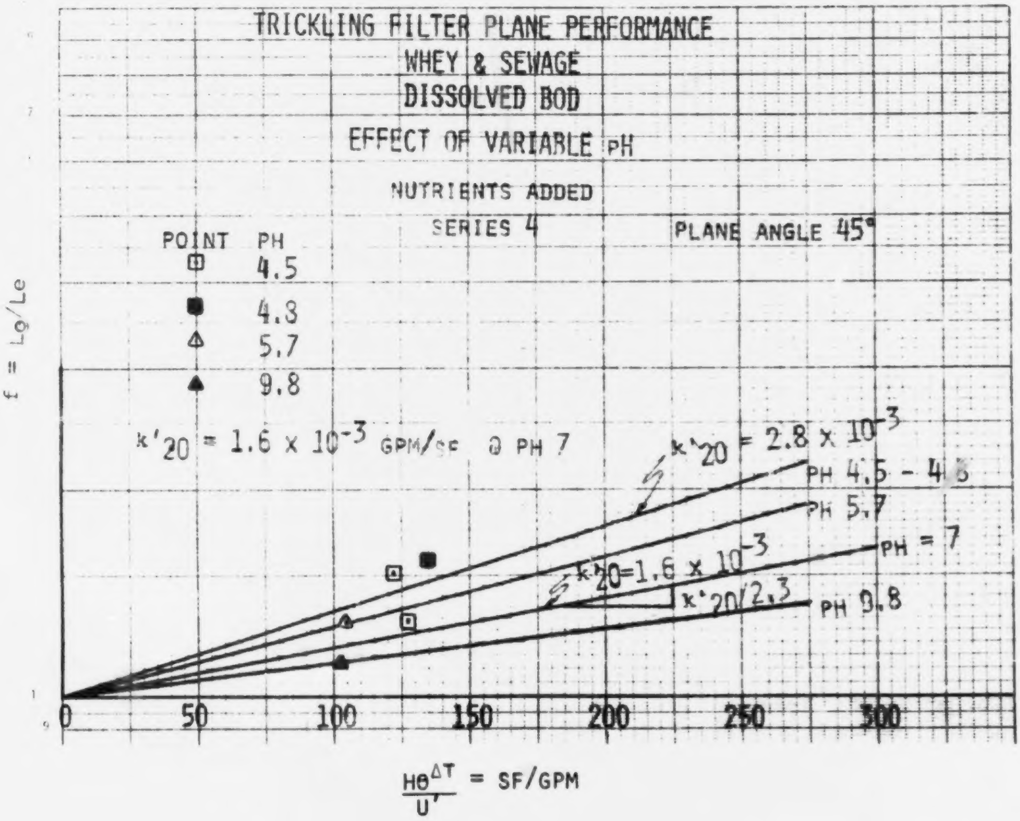


FIGURE 13

TRICKLING FILTER PLANE PERFORMANCE
WHEY & SEWAGE, DISSOLVED BOD
EFFECT OF RECYCLE

FIGURE 14


TRICKLING FILTER PLANE PERFORMANCE
WHEY & SEWAGE
DISSOLVED BOD
EFFECT OF VARIABLE pH
NUTRIENTS ADDED
SERIES 4
PLANE ANGLE 45°
POINT PH
⊡ 4.5
■ 4.3
△ 5.7
▲ 9.8
k'20 = 1.6 x 10-3 GPM/SF @ PH 7
k'20 = 2.8 x 10-3
PH 4.5 - 4.8
PH 5.7
PH = 7
k'20=1.6 x 10-3
k'20/2.3
PH 9.8
f = Lo/Le
0
50
100
150
200
250
300
HθΔT / U' = SF/GPM

A series of experiments was made over the temperature range from 19 to 30°C. The results of the experiments are presented graphically as Figures 15 and 16. The value of k' increased with temperature from 1.6×10^{-3} gpm/SF at 20°C to 2.2×10^{-3} gpm/SF at 29°C. The average value of θ was computed as 1.035 and was in agreement with value assumed in current practice.

Model Verification

Figure 17 is a presentation of biological filter plane results obtained with a feed pH of 7 and a plane angle of 30°. The excellent linearity of the plot over the wide range of operating conditions, including different plane lengths, verifies the applicability of the proposed kinetic formulation for description of biological filter performance. For the conditions represented by the plot, the BOD removal rate coefficient, K_{20}, was computed as 1.6×10^{-3} gpm/SF.

The analytical technique developed prior to this study and extended during study execution was such as to allow direct computation of BOD removal rate constants from laboratory simulations of trickling filter surfaces. The literature was reviewed for whey data to which the correlation could be applied. The data of Schultze [31] were analyzed for whey application over a vertical surface comprised of a screen mesh. The correlation is shown on Figure 18 and supports a (k') value of 1.6×10^{-3} gpm/SF over a temperature range of 14° to 22°C, and a BOD removal efficiency from 25% to 80%.

Summary of Filter Plane Performance

A summary of all laboratory runs for BOD and COD removals on the trickling filter planes is presented in the Appendix. Data are subdivided into series as follows:

1. A given plane condition was set, i.e., angle, length, flow, rate, temperature, pH and nutrient addition.
2. After 24 and 48 hours, grab samples were taken for analysis.

Each grab sample was considered a run. A total of 47 runs or daily grab samples was obtained during the study. The runs were divided into series according to the major parameter of study (Table 22).

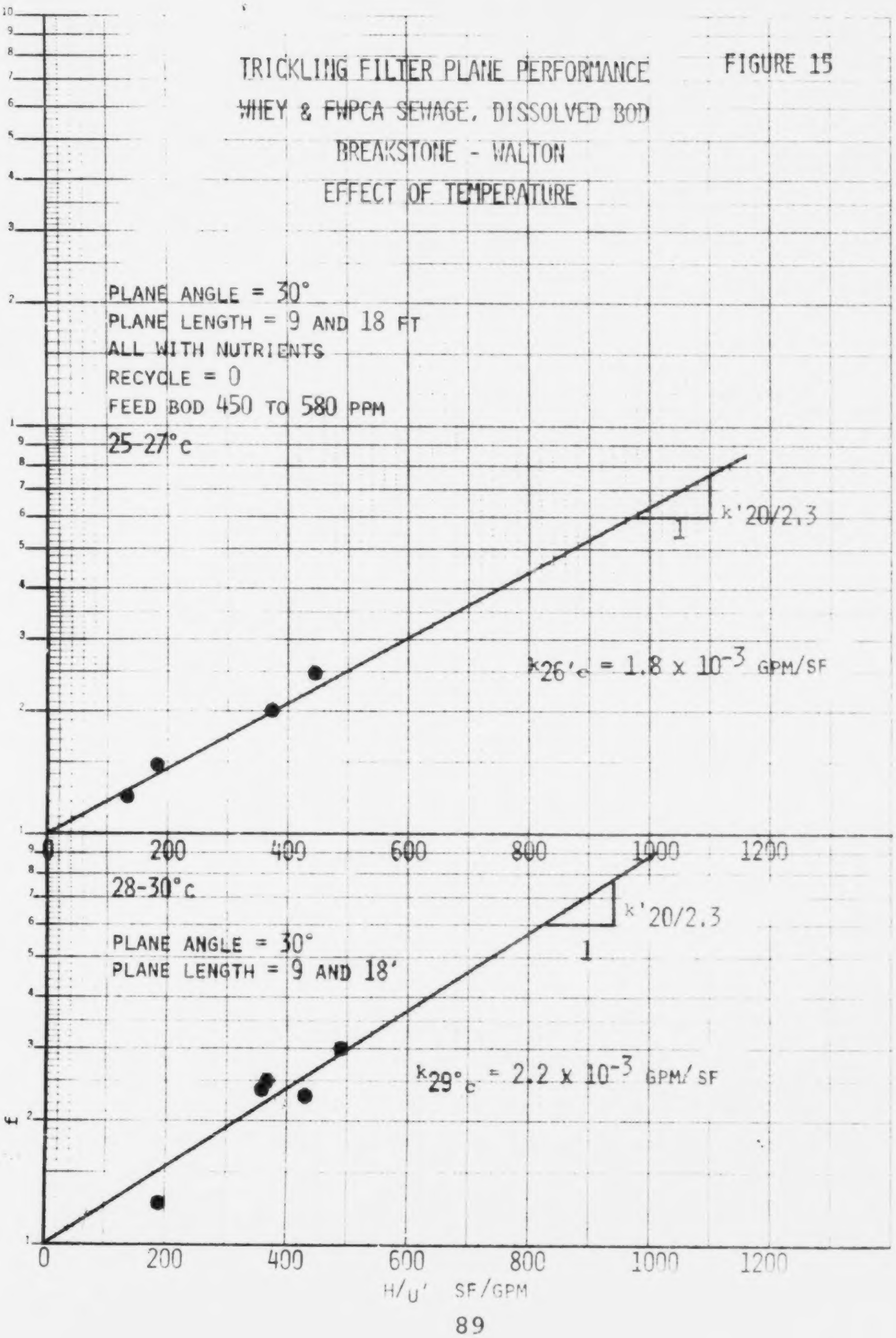


FIGURE 15

TRICKLING FILTER PLANE PERFORMANCE
WHEY & FWPCA SEWAGE, DISSOLVED BOD
BREAKSTONE - WALTON
EFFECT OF TEMPERATURE

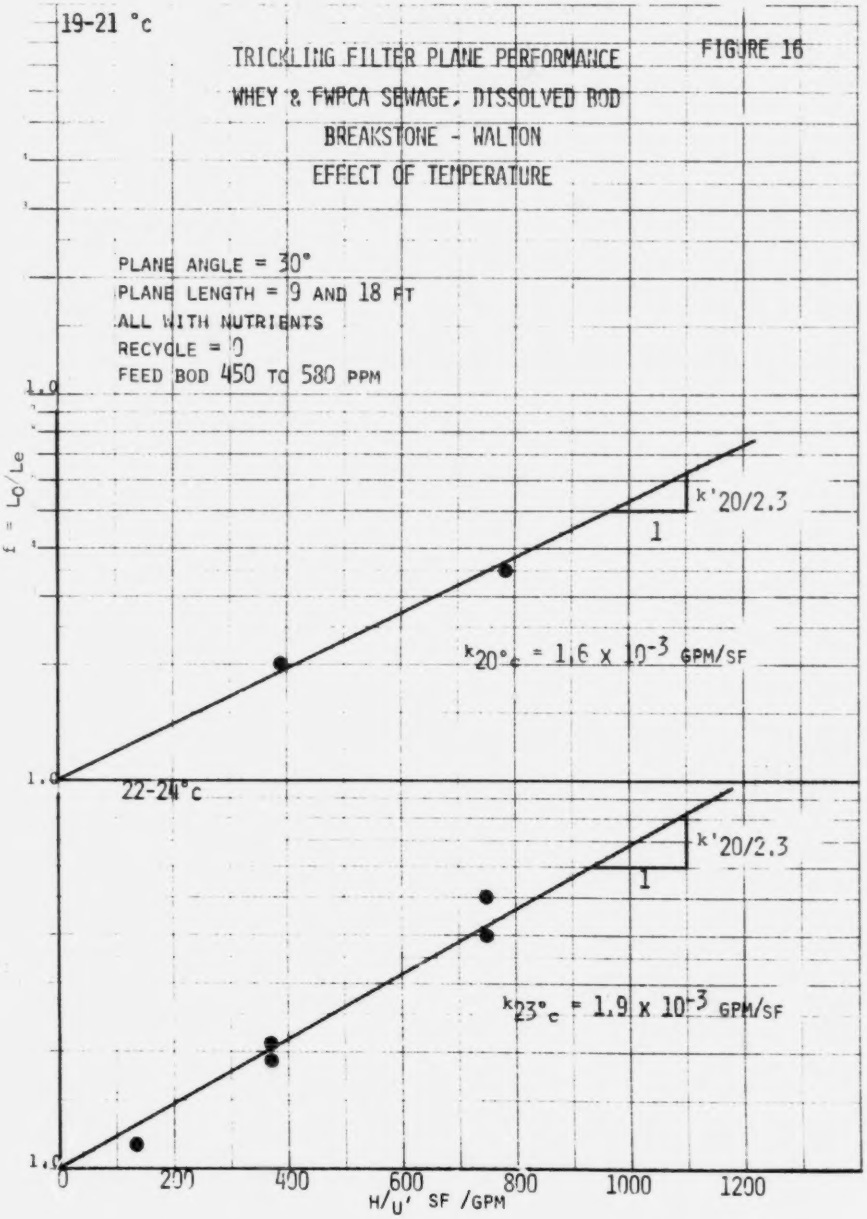
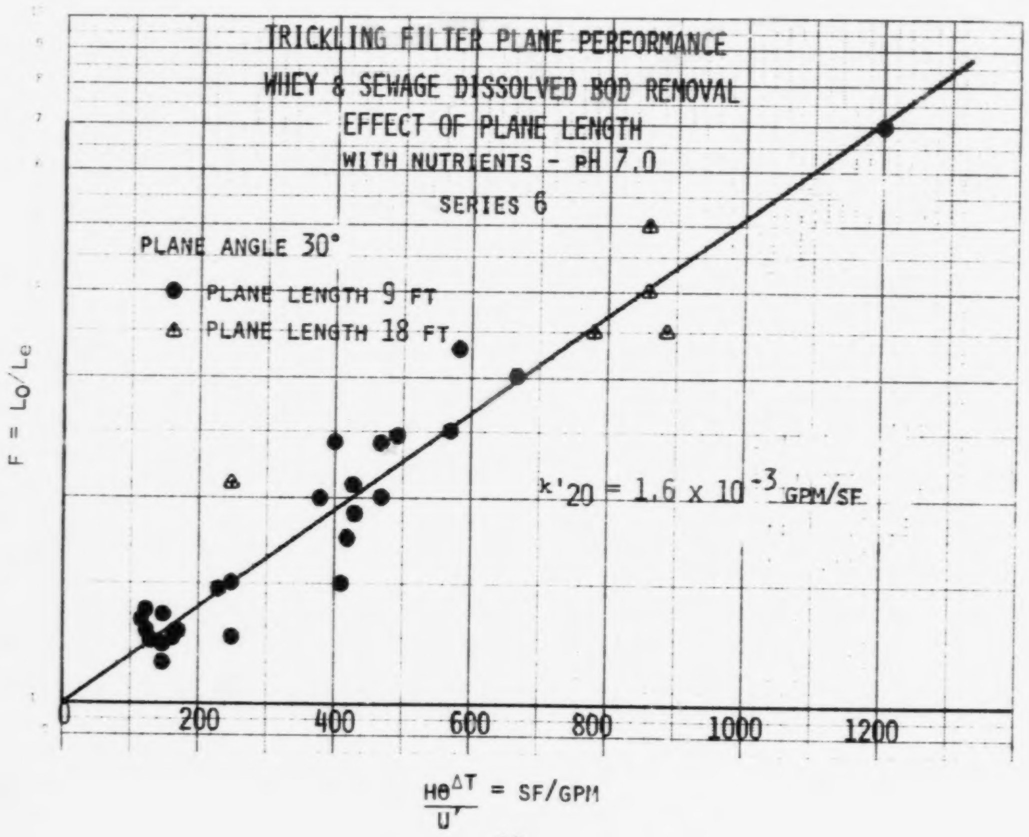

19-21 °C
TRICKLING FILTER PLANE PERFORMANCE
WHEY & FWPCA SEWAGE, DISSOLVED BOD
BREAKSTONE - WALTON
EFFECT OF TEMPERATURE
FIGURE 16
PLANE ANGLE = 30°
PLANE LENGTH = 9 AND 18 FT
ALL WITH NUTRIENTS
RECYCLE = 0
FEED BOD 450 TO 580 PPM
1.0
f = Lo/Le
k'20/2.3
1
k20°C = 1.6 x 10-3 GPM/SF
1.0
22-24°C
k'20/2.3
1
k23°C = 1.9 x 10-3 GPM/SF
1.0
0
200
400
600
800
1000
1200
H/U' SF /GPM

FIGURE 17


TRICKLING FILTER PLANE PERFORMANCE
WHEY & SEWAGE DISSOLVED BOD REMOVAL
EFFECT OF PLANE LENGTH
WITH NUTRIENTS - pH 7.0
SERIES 6
PLANE ANGLE 30°
● PLANE LENGTH 9 FT
△ PLANE LENGTH 18 FT
k'20 = 1.6 x 10^-3 GPM/SF
F = Lo/Le
0
200
400
600
800
1000
1200
HθΔT/U' = SF/GPM

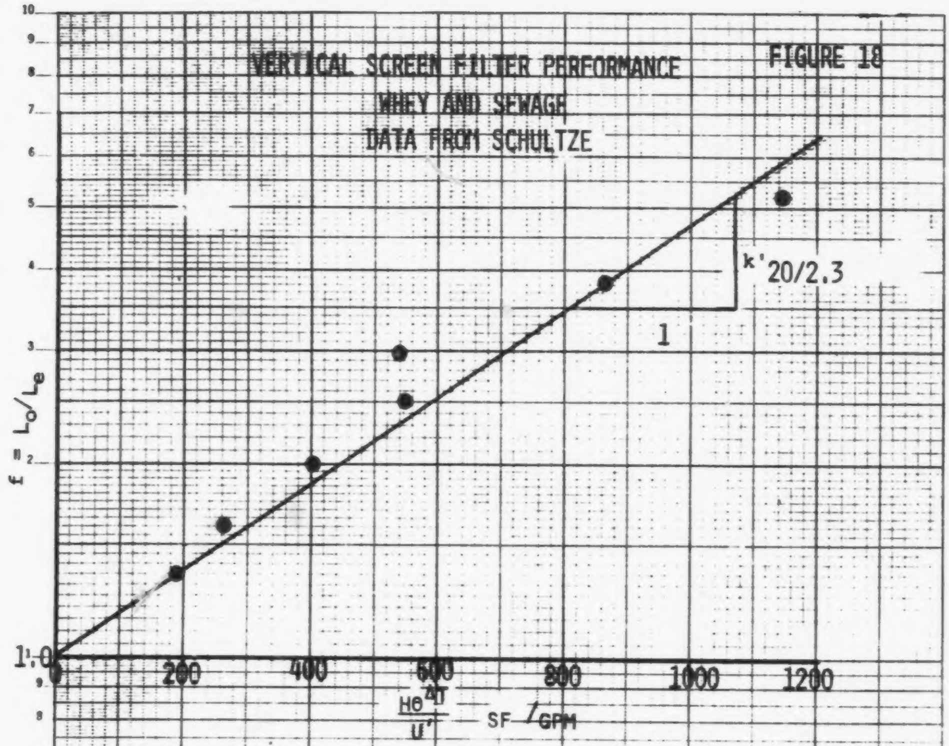


FIGURE 18

VERTICAL SCREEN FILTER PERFORMANCE
WHEY AND SEWAGE
DATA FROM SCHULTZE

SCHULTZE DATA AS FOLLOWS:

U'/H GPM/SF	I	°C	E%
.035	0	20.6	81.0
.0420	0	15.8	74.0
.0630	0	14.1	66.7
.0810	0	21.3	59.7
.1120	0	22.1	50.0
.1675	0	21.4	38.9
.2300	0	20.2	25.8

TABLE 22

Summary of Filter Plane Performance

	Plane Geometry					
Series	Angle (°)	Length (ft)	Nutrients	pH	Number of Runs	Parameter Studies
1	45 & 30	9	No	7	7	Study of Nutrient Addition
2	45 & 30	9	Fe only	7	4	
3	45	9	N only	7	2	
4	45	9	All	Variable	4	pH Study
5	45	9	All	7	6	Study of Angle
6	30	9 & 18	All	7	14	

Note: *Series 6 run 12a, 13a and 14a are the first 9 ft of 18-ft planes evaluated in runs 12, 13 and 14.*

Computer Program for Laboratory Data Analysis

The purpose of this computer program is to summarize the trickling filter operation data, compute the trickling filter kinetics, and prepare the kinetic correlations. This use was based on the ability of the computers to operate at great speed, to produce accurate results, to store large quantities of information, and to carry out long and complex sequences of operations without human intervention. Appendix 2 contains a copy of the program printout. This program which has been named WHEYTF consists of one main program, TRIFIL, and three subroutines, PLOT, PLOTHD, and LEASQS.

In the main program, TRIFIL, comments and new data were read and printed, unit conversions for raw data were executed and printed. BOD or COD fed to the plant included recirculation, BOD or COD removal efficiency, recirculation ratio, theoretical detention time of waste on the plane. All the correlation parameters were computed and tabulated. Subroutines were called to plot the kinetic correlations, locate the lines of best fit, and compute the various reaction constants. Kinematic viscosity and temperature relationships were expressed by three linear relationships. All the correlation parameters were computed under the assumption of negligible evaporation.

In the subroutine PLOT, kinetic correlations were plotted. Two graphs were drawn for the first order reaction while only one was plotted for the simple retardant reaction. The subroutine sorted the abscissa-array (x-array) in ascending order, computed minimum and maximum values in x-array and Y-array (ordinate-array), checked the increment on Y-axis, called the subroutine PLOTHD, printed out ordinate axis, plotted out the values along with the x-axis, and called the subroutine PLOTHD again.

The subroutine PLOTHD printed out the heading of the plot, the variables plotted and the kinetic model selected.

The last subroutine LEASQS employed the method of least squares to compute the slope and the intercept of the line of best fit on each plot. The subroutine also computed the reaction constants involved.

Description of Input

In this program, run identification or project name and/or number was input first, followed by number of pieces of data, type of plant, kinetic model selected, output device used, plane length or tower height, operation data and the width and inclined angle of plane or the diameter of tower. The operation data included raw waste BOD or COD, effluent BOD or COD, recirculation rate, raw waste flow rate and temperature. The data formats are as follows:

```
NC
(AA(J), J= 1, 16)
(AA(J), J= 1, 16)
                              Total NC cards or lines
(AA(J), J= 1, 16)
N, NTYP, NK, LL
HL
(CA(I), I= 1, N)
(CE(I), I= 1, N)
(R(I), I= 1, N)
(Q(I), I= 1, N)
(T(I), I= 1, N)
W, A for planes or D for towers
```

where:

NC = number of cards or lines for run identification, project name, project number or other comments

AA = Run identification, project name, project number or other comments

N = Number of pieces of data

NK = 1 if first order reaction is selected
= 3 if simple retardant reaction is chosen
= 5 if Michaelis-Menton relationship is employed

NTYP = 1 if plane is employed
= 2 if tower is used

LL = 1 if teletype is employed
= 2 if DCT is used

HL = plane length or tower height in ft

CA = raw waste BOD or COD in ppm

CE = effluent BOD or COD in ppm

R = recycle flow in ml/min for planes, or in gpm for tower

Q = raw waste flow in ml/min for planes, or in gpm for towers

T = temperature of waste in °F

W = width of plane in in.

A = angle of plane with horizon in degrees

D = diameter of tower in ft

Description of Output

The program output included the following four components: (1) input data tabulation with both original and converted units and list of some computed values, i.e., BOD or COD fed to the plant including recirculation, BOD or COD removal efficiency, recirculation ratio, theoretical detention time of waste on the plane; (2) tabulation of kinetic model correlation parameters; (3) graphs of model correlations; and (4) values of the slope and intercept of the line of best fit and the reaction constants.

First Order Reaction

A sample printout of the program result for first order reaction is shown in the output of DATAZI. Two plots were drawn. One was log f (ordinate) vs. $H\theta^{\Delta T}/U$" (abscissa) for planes or log f vs. $H\theta^{\Delta T}/U$ for towers. The slope of the line was $k'/2.3$ for planes or $k'A'_V/2.3$ for towers. The other plot was log $H\theta^{\Delta T}/$ log f vs. log U for towers. The slope of the line represented the hydraulic loading exponent n, and the intercept on the ordinate (log($H\theta^{\Delta T}$/log f) axis) was log $(2.3/k')$ for planes or log $(2.3/k'A'_V)$ for towers.

Simple Retardant Reaction

A sample printout for the simple retardant reaction is shown in the output of DATA 22. The relationship of f vs. $H\theta^{\Delta T}/U$" (planes) or f vs. $H\theta^{\Delta T}/U$(towers) was plotted. The intercept on the ordinate of the line of best fit had to be unity. The slope of the line of best fit represented k' for planes or $k'A'_V$ for towers.

Effluent pH and Neutralization

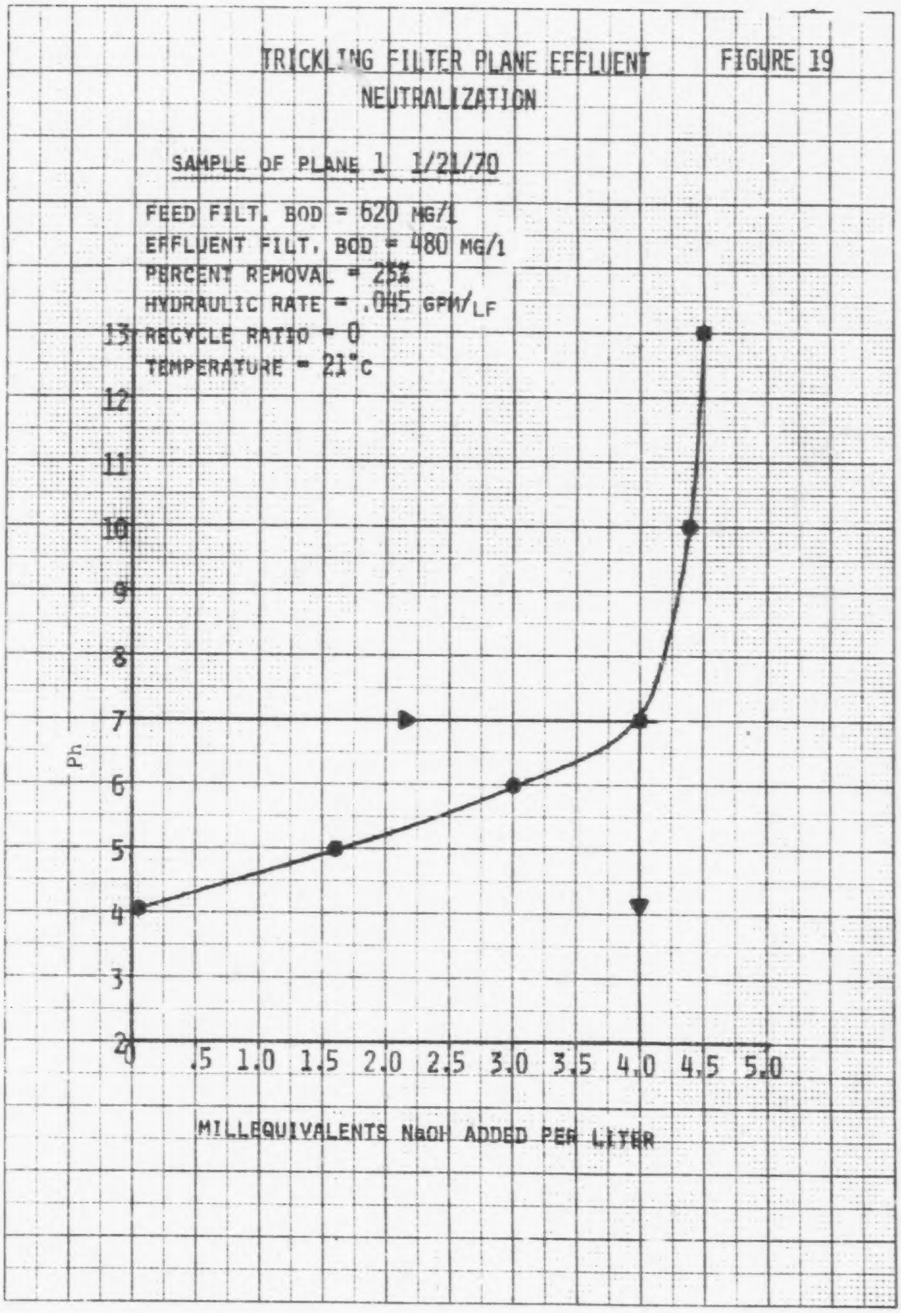
All sewage-whey process influents were adjusted to pH 7 during this study. Grab sample effluent analysis showed a tendency toward depressed pH with decreasing treatment. For example, with 10% to 30% BOD removal, the effluent pH was 4-5, but with 60% to 75% BOD removal, the effluent pH was near neutral. Figure 19 illustrates a titration curve for a pH depressed, high BOD effluent. 4 me/l of base were required to raise the pH from 4 to 7.

Calculated lime additions to raise this effluent sample to pH 7 are 150 mg/l. Qualitative observation of the effect of lime addition showed floc formation and improved sedimentation with lime additions as low as 25 mg/l.

Properties of Suspended Solids

In the analysis of wastewater and effluent, it is useful, for conceptual purposes, to segregate suspended and dissolved fractions of BOD. The concept assists in the visualization of BOD removal by settling facilities and in the appraisal of effluent characteristics.

The results of determinations of BOD equivalency of the feed and effluent suspended solids from treatment of whey wastes



TRICKLING FILTER PLANE EFFLUENT NEUTRALIZATION

FIGURE 19

SAMPLE OF PLANE 1 1/21/70

FEED FILT. BOD = 620 MG/1
EFFLUENT FILT. BOD = 480 MG/1
PERCENT REMOVAL = 25%
HYDRAULIC RATE = .045 GPM/LF
RECYCLE RATIO = 0
TEMPERATURE = 21°C

are given in Figure 20. The BOD equivalences for the suspended solids were 0.63 and 0.62 lbs BOD per lb suspended solids, respectively, for feed and effluent.

These values are employed to determine the following:

1. The dissolved BOD of untreated waste by deducting suspended BOD values from total BOD measurements.
2. The dissolved BOD of treated effluent by deducting the suspended BOD corresponding to effluent suspended solids limitations from the total BOD requirement.
3. The dissolved BOD removal required of the trickling filters.

Examples of these computations are shown on Table 2.

Supplementary determinations of volatile content of feed and effluent suspended solids were made. These results are presented as Figure 21. Feed and effluent suspended solids were 87% and 88% volatile, respectively.

Solids-Liquid Separation

Several tests were performed on the laboratory trickling filter effluents to determine sedimentation characteristics. Effluent samples were settled for various detention times in a standard 500 ml polyethylene cylinder. Supernatant samples were withdrawn at the 150 ml level.

Figure 22 illustrates the supernatant suspended solids after varying detention times for a given trickling filter plane operating condition with differing effluent suspended solids. At 150 mg/l effluent suspended solids, the supernatant stabilized after 60 minutes at 85 mg/l. At 78 mg/l effluent suspended solids, the supernatant stabilized after 30 minutes at 60 mg/l.

Eleven settling tests, summarized in Table 23, were conducted at various trickling filter plane operating conditions for differing effluent suspended solids concentrations at 30 minutes detention time. The average effluent suspended solids concentration was 160 mg/l ranging from 550 to 42 mg/l. Supernatant suspended solids after 30 minutes average 100 mg/l ranging from 200 to 30 mg/l.

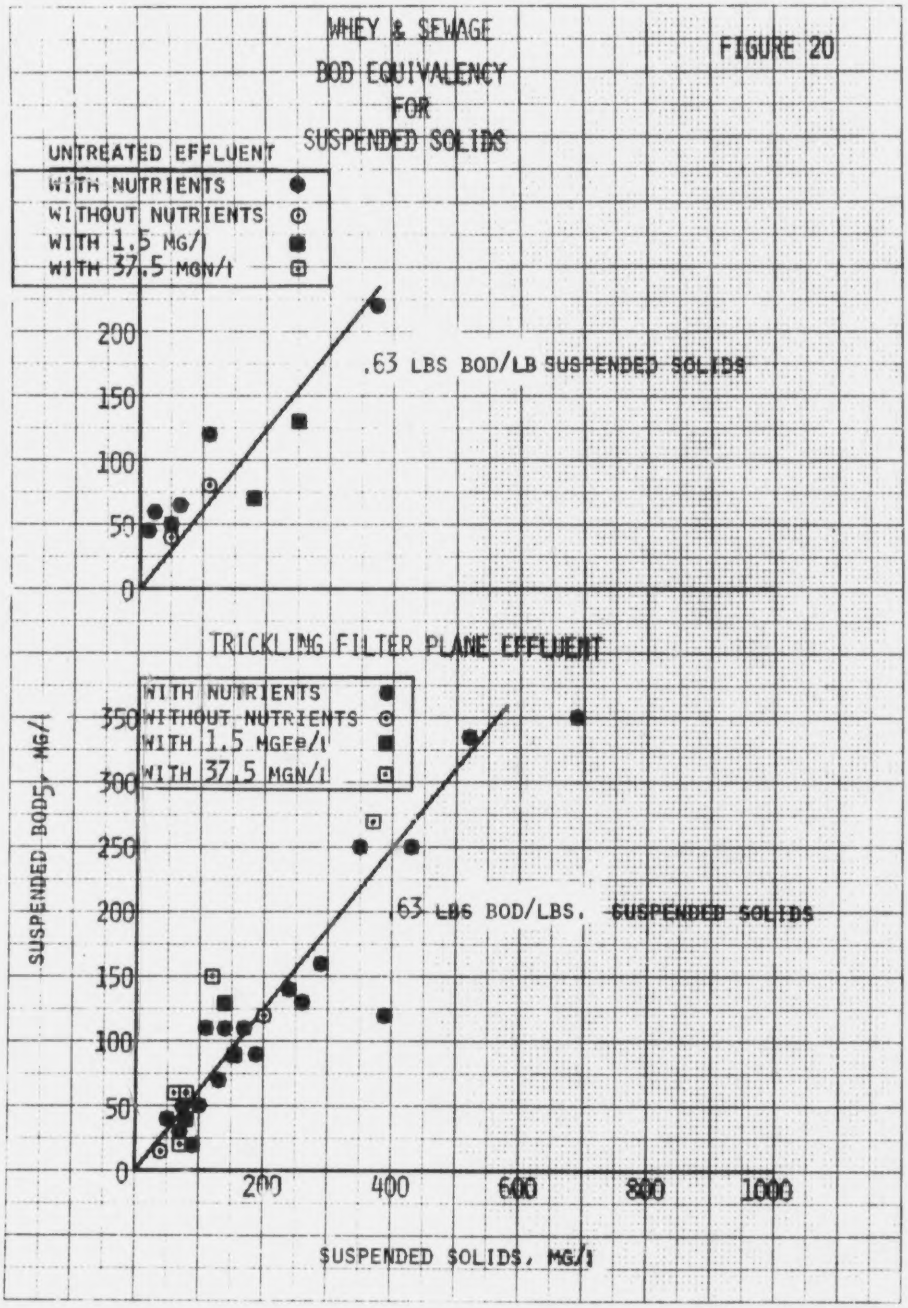


FIGURE 20

WHEY & SEWAGE
BOD EQUIVALENCY
FOR
SUSPENDED SOLIDS

WHEY & SEWAGE

FIGURE 21

VOLATILE SUSPENDED SOLIDS CONTENT

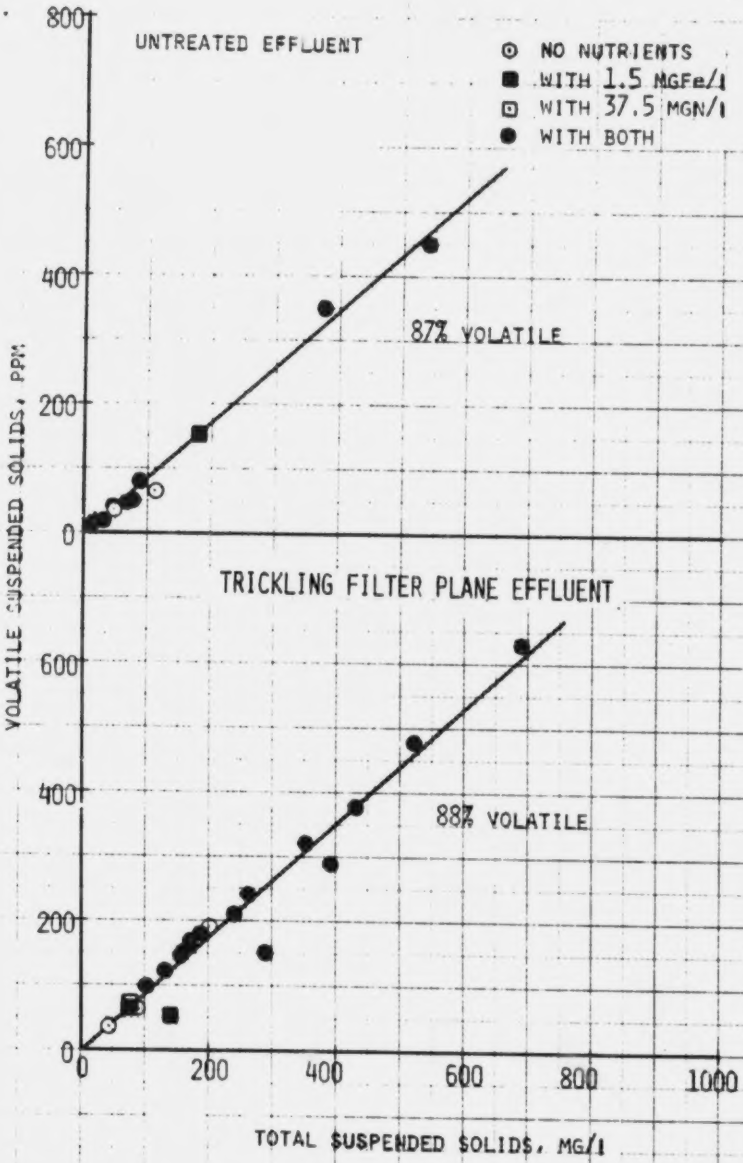


FIGURE 22

TRICKLING FILTER PLANE EFFLUENT
FINAL SEDIMENTATION TESTS

PLANE OPERATING PARAMETERS

POINT	HYDRAULIC LOAD (GPM/LF)	RECYCLE RATIO	TEMP °C	% BOD REMOVAL
●	.095	2	30	50
⊕	.095	2	29	40

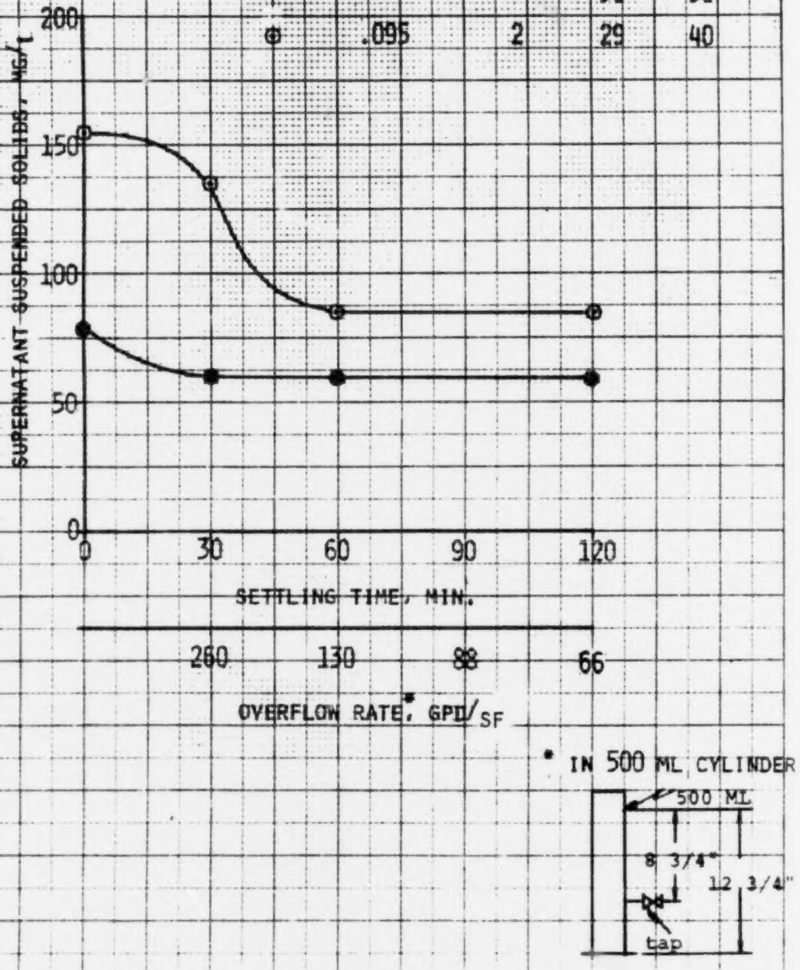


TABLE 23

Final Sedimentation Trickling Filter Plane Effluent Whey and Sewage

500 ml Cylinder

Test Apparatus

1. Description - 500 ml Graduated Cylinder
2. Total Depth - 12-3/4 in.
3. Sample Depth for Sludge Removal - 8-3/4 in.
4. Detention Time - 30 min
5. Overflow Rate (Equivalent) - 260 gpd/hr

Results

	Maximum	Average	Minimum
1. Initial Suspended Solids (mg/l)	550	160	42
2. Percent Volatile	-	80	-
3. Temperature (°C)	25	20	14
4. Supernatant			
a. Suspended Solids (mg/l)	200	100	30
b. Percent Volatile	-	84	-
5. Percent Removal Suspended Solids	-	37.5	-

The average of all effluent suspended solids determined during this study was 360 mg/l. Samples were taken only during times when planes were 90% to 100% covered with slime as whey exhibits a high growth rate of organisms.

Based on the data illustrated in Figure 22, a detention time of 60 minutes in the test cylinder (130 gpd/SF) would remove all the settleable solids. Projecting the data of Figure 22 and Table 23, a supernatant suspended solids concentration of between 75 and 100 mg/l would be expected from gravity sedimentation.

Relationship Between BOD and COD

The BOD test is of more significance than the COD test, but the COD test is more rapid and more precise. With certain wastes, it is possible to obtain satisfactory correlation between BOD and COD to enable routine estimation of BOD from COD determinations.

Correlations between BOD and COD for whey waste influent and effluent are given in Figure 23. The correlations were sufficiently reliable to enable useful estimation of BOD from COD within the range of the data. Generally, the BOD was about 60% of the COD, irrespective of whether nutrient supplementation was added.

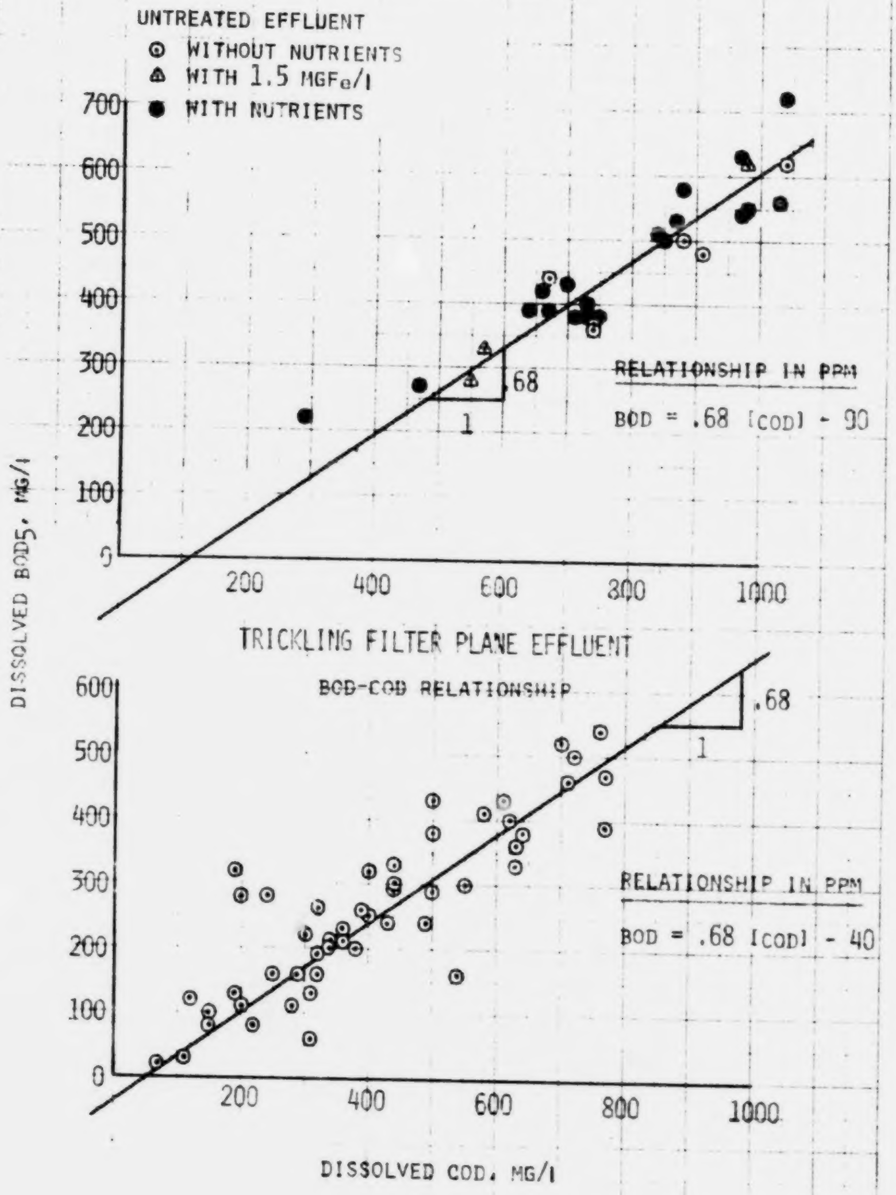
Odor Control

Dairy wastes are often characterized by butyric-acid odors caused by the decomposition of casein. Appreciable odor in whey-bearing wastes from cheese production was reported by Ingram [16]. Fraser [11] reported odors from a high-rate single-stage trickling filter treating the effluent from a dairy factory in Australia. He proposed that the odors were due to anaerobic metabolism in thick slime layers.

To prevent odorous nuisance conditions developing, the trickling filter planes were enclosed and facilities provided to deodorize the effluent air stream. A minimum air flow of 40 CF/gal. was provided. Total air flow over the four trickling planes averaged 40 CF/hr. A Welsbach model T-816 laboratory ozonator was chosen as the ozone source. Its rated capacity of 8 gms ozone per hr using air as the feed gas insured adequate capacity over and above the 10 ppm dosage recommended by the manufacturer for deodorizing sewage sludges. Ozone production control was accomplished

FIGURE 23

WHEY & SEWAGE
BOD - COD RELATIONSHIPS



using a Welsbach model H-81 ozone meter. A minimum reactor detention time of 5 minutes was provided before exhausting the deodorized air effluent outside the laboratory.

During the experimental work, odor was detected only at the higher BOD loadings, above .036 lbs BOD/day-SF area or converting to Surfpac prototype units above approximately 1,000 lbs BOD/day 1,000 CF. Application of ozone at an approximate dosage of 10 ppm effectively deodorized the effluent air stream. No evidence of odor was detected either in the laboratory or at the air effluent exhaust.

On-Site Pilot Plant

Trickling filter studies on a pilot plant scale were performed at Walton, New York on the site of the Breakstone mill. The pilot plant was used to treat Breakstone effluent and Breakstone effluent combined with settled sewage. The principal function of the on-site pilot plant was the generation of secondary sludge on a scale sufficient to enable the development of practical dewatering and disposal processes. As a matter of general interest, and for control purposes, some data were collected relative to the influence of operating variables on pilot plant performance. Table 24 presents a summary of characteristics of each effluent. Urea fertilizer was added to the waste as nitrogen supplement. The dosage was 2.0 lbs/day as N. The correlation of BOD and COD for the Breakstone effluent was described by the relationship:

$$\text{BOD} = 0.75[\text{COD}] - 40 \ldots\ldots\ldots\ldots\ldots\ldots (\#37)$$

Pilot Plant Description

The pilot plant flow sheet at Walton consisted of a primary settling tank followed by trickling filtration and batch settling of filter effluent as shown on Figure 24.

The trickling filter was supplied by the Koch Engineering Company, Inc. The unit, Figure 25, has a cross-sectional area of 7 SF and a media of depth of 18 to 20 ft. The packing media was Koch Flexirings, a 3.5-in. plastic, webbed cylinder with a specific surface of 28 SF/CF. The unit was capable of receiving a wide range of raw waste flows and a similar range of effluent recirculation flows, i.e., up to 2.5 gpm/SF in each case.

TABLE 24

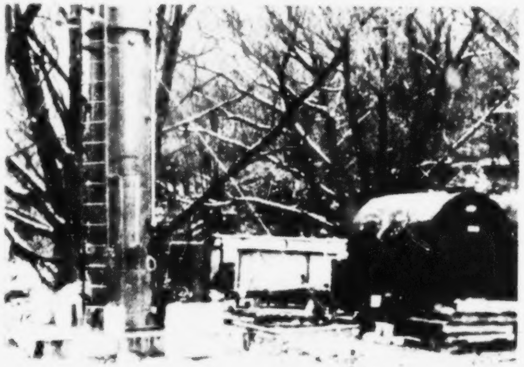
Characteristics of Pilot Plant Influent

Characteristic	Whey Effluent		Whey and Sewage**	
	Average	Range	Average	Range
Suspended Solids, ppm	240	770-41		
Total BOD, ppm*	830	1,593-440		
Soluble BOD, ppm	560	1,075-170	241	310-172
Soluble BOD, %	76			
Suspended BOD, ppm	173			
BOD Equivalent of Suspended Solid	0.72			
Total COD, ppm*	1,440	2,390-840	451	595-307
Soluble COD, ppm	841	1,490-264		
Soluble COD, %	74			
Suspended COD, ppm	300			
COD Equivalent of Suspended Solids	1.25			
pH		5.5-7		6-7

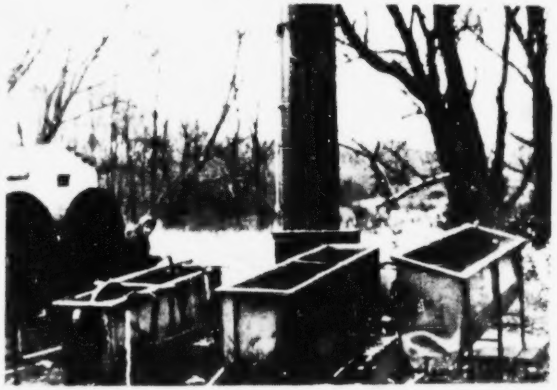
*This characteristic is taken from a smaller data population than the other characteristics.

**Primary effluent from the Village of Oneonta was used to simulate the combined waste.

FIGURE 24



PACKED TOWER BASE & SEWAGE STORAGE TANKS



PRIMARY SETTLING TANK (LEFT)
TWO BATCH SECONDARY SETTLING TANKS (RIGHT)

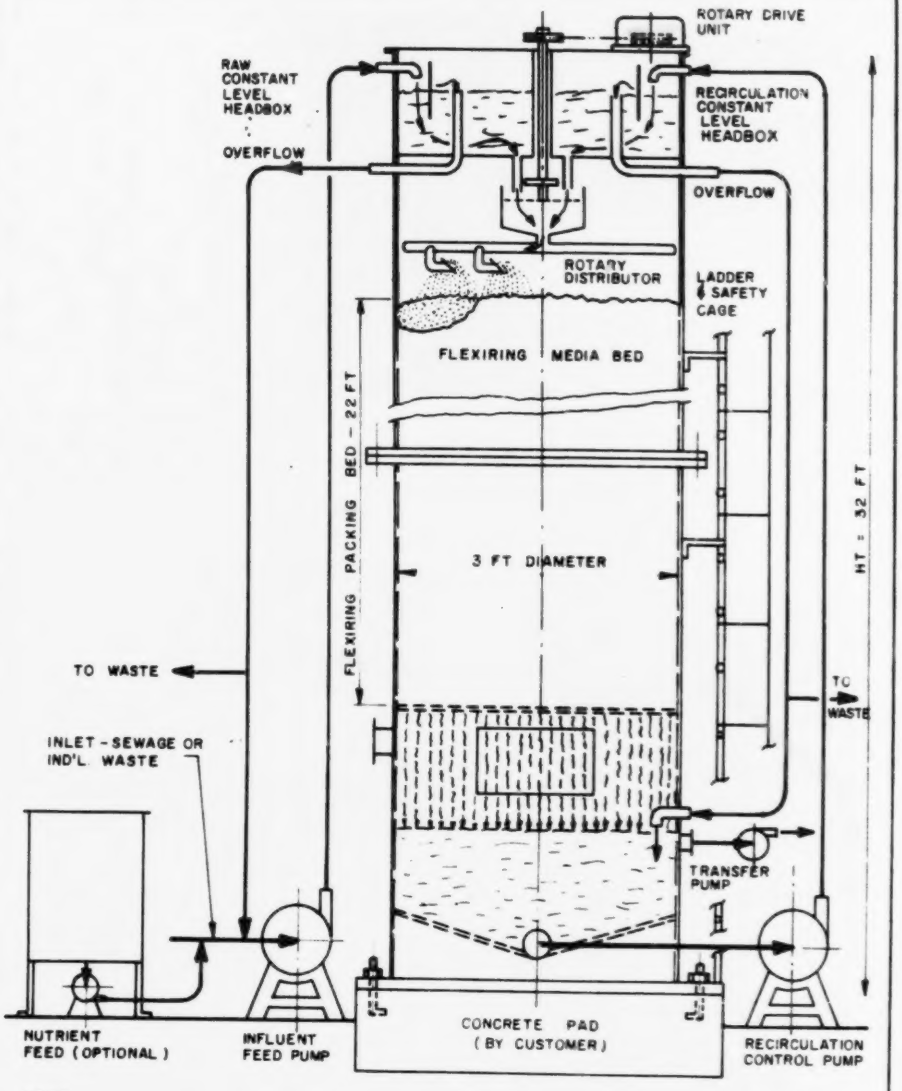
PACKED TOWER, FULL LENGTH

TRICKLING FILTER PILOT PLANT

WALTON, NEW YORK

QUIRK, LAWLER & MATUSKY ENGINEERS

FIGURE 25


ROTARY DRIVE UNIT
RAW CONSTANT LEVEL HEADBOX
RECIRCULATION CONSTANT LEVEL HEADBOX
OVERFLOW
OVERFLOW
ROTARY DISTRIBUTOR
LADDER & SAFETY CAGE
FLEXIRING MEDIA BED
FLEXIRING PACKING BED - 22 FT
HT = 32 FT
3 FT DIAMETER
TO WASTE
TO WASTE
INLET - SEWAGE OR IND'L. WASTE
TRANSFER PUMP
CONCRETE PAD (BY CUSTOMER)
NUTRIENT FEED (OPTIONAL)
INFLUENT FEED PUMP
RECIRCULATION CONTROL PUMP

NOTE

1. PUMPS & ELECTRICAL CONTROLS ARE MOUNTED ON A CONTROL PANEL SKID
2. BASIC PIPING IS PREASSEMBLED

KOCH FLEXIRING
PILOT PLANT

Pilot Plant Experimental Procedures

The pilot plant was operated for a period of about 2-1/2 months. The operating period can be divided into the following phases.

1. An acclimation phase for growth of slime with occasional grab samples for evaluation of acclimation.
2. Short periods (less than 1 day) for evaluation of trickling filter detention time and BOD removal performance at high hydraulic and high organic loading rates.
3. Long periods (4 to 7 days each) of applying Breakstone waste at constant hydraulic loading rates for evaluation of secondary sludge characteristics and BOD removal performance.

The primary and final settling tanks were not evaluated for treatment performance. Samples collected for evaluation of filter performance were collected directly from the influent and effluent flows. The filter was evaluated for BOD and COD removal with a distinction between the solid and liquid phases.

The majority of trickling filter samples were continuous composites for periods of typically 3 to 5 hrs. Grab samples were taken for shorter filter runs.

The samples were analyzed on the day following their collection. Preservation was accomplished by acidification and refrigeration during transit and prior to analysis.

Sludge samples were obtained by collection of effluent into two 350-gal. settling tanks operated on a batch basis. After filling, the tanks were mixed and allowed to settle quiescently for 1 hr. At the end of the settling period, the supernatant liquid was pumped to waste and the sludge was collected for shipment. Refrigerated samples of sludge were transported to laboratories for analysis and evaluation.

Pilot Plant Performance

A summary of results relating to the performance of the biological filter pilot plant is given in Tables 25 and 26.

TABLE 25

Summary of Trickling Filter Pilot Plant Performance Whey Effluent

Run No.	Waste Characteristics			Average Temperature (°C)	Geometry	Hydraulic Conditions		Effluent Characteristics			Results	
	Soluble COD (ppm)	Soluble BOD (ppm)	BOD from COD (ppm)		Height H (ft)	U gal./min (SF)	Recycle Ratio (r)	Soluble COD (ppm)	Soluble BOD (ppm)	BOD from COD (ppm)	COD Removal (%)	BOD Removal (%)
1	930	700		18	18	.77	0	490	370		47	47
2	1,190	860		18	18	1.17	0	950		670	20	22
3	287	192		18	18	1.64	0	530	408		<0	<0
4	350		260	19	18	2.76	0	302		220	14	15
5	1,290		830	18	20	1.18	0	890		640	31	23
6	264	170		16	20	2.12	0	176	106		33	38
7	480	415		11	20	1.24	19.5	338	117		30	72
8	310	283		11	20	1.24	19.5	424	145		<0	49
9	1,150	700		10	20	1.24	19.5	382	262		68	63
10	470	320		10	20	1.24	19.5	184	52		61	84
11	555		430	9	20	1.24	19.5	260		190	53	56
12	480		370	9	20	1.24	19.5	236		165	51	55
13	580	404		9	20	.93	6.1	165	128		72	68
14	720	440		11	20	.98	4.4	118	63		84	86
15	1,360	775		16	20	.99	4.2	250	156		82	80

TABLE 25

(continued)

	Waste Characteristics				Geometry	Hydraulic Conditions		Effluent Characteristics			Results	
Run No.	Soluble COD (ppm)	Soluble BOD (ppm)	BOD from COD (ppm)	Average Temperature (°C)	Height H (ft)	U gal./min (SF)	Recycle Ratio (r)	Soluble COD (ppm)	Soluble BOD (ppm)	BOD from COD (ppm)	COD Removal (%)	BOD Removal (%)
16	508	365		13	20	1.00	2	163	118		68	68
17	1,200	717		15	18	1.10	3.1	590	407		51	43
18	1,050	630		13	18	1.10	3.1	337	240		68	62
19	1,610	950		13	18	1.10	2.7	770	550		52	42
20	860		630	20	18	1.20	3.8	378		290	56	54
21	1,070	670		15	18	1.10	3.1	400		300	63	55
22	1,490	1,075		14	18	1.10	3.1	670		520	55	52
23	2,350				18	1.10	1.0	670		520	71	
24	1,620		990	16	18	1.10	1.0	680		530	58	46
25	1,300		840	16	18	1.10	1.0	512		390	61	54
26	790	640		11	18	1.10	1.0	575		450	27	30
27	750	560		18	18	1.65	2.0	264		190	65	66

TABLE 26

Summary of Trickling Filter Pilot Plant Performance
Whey and Sewage Effluent

	Waste Characteristics				Geometry	Hydraulic Conditions	
Run No.	Soluble COD (ppm)	Soluble BOD (ppm)	BOD from COD (ppm)	Average Temperature (°C)	Height H (ft)	U gal./min (SF)	Recycle Ratio (r)
1	595	310		15	20	.68	0
2	307	172		12	20	.68	0

	Effluent Characteristics			Results	
Run No.	Soluble COD (ppm)	Soluble BOD (ppm)	BOD from COD (ppm)	COD Removal (%)	BOD Removal (%)
1	346	75		42	76
2	234	120		24	30

The results are presented graphically in Figure 26 to illustrate the relationship between BOD removal and BOD loading. Substantial scatter of points was evident, but a trend for better than 50% removal was exhibited for BOD loadings of less than 150 ptcfd.

Erratic performance was attributed in part to plugging of the media due to the extensive slime growth effected at high loadings. Poor performance, black sludge and poor draft in smoke tests were evidence that the pilot plant was occasionally affected by anaerobic conditions.

Media Detention Time

A detention time study was performed to insure that pilot plant residence time was within the range anticipated for full scale and to evaluate the parameters for residence time correlation. A concentrated sodium chloride solution was added to the influent and traced in the effluent samples by measuring specific conductance. Effluent samples were taken at various intervals, usually 10 seconds, until the specific conductance was close to the background value measured before the salt was added. Six hydraulic loadings of .775, 1.17, 1.18, 1.64, 2.12 and 2.76 gpm/SF were used for determining the detention time for each (with slime on the media). Hydraulic loading was taken as the time from dosing to the centroid of the effluent concentration-time curves.

Figure 27 is a logarithmic plot of detention time versus hydraulic loading. Two lines are fitted through the six points. The dotted line assumes that the minimum wetting rate, i.e., the flow required to fully utilize the available surface area, is less than or equal to .775 gpm/SF. The solid line assumes that the minimum wetting rate is less than or equal to 1.17 gpm/SF and therefore, was fitted, without the first point. Based on manufacturer's estimation that minimum wetting rate for the 3.5-in. Flexirings is 1 gpm/SF, the values of N' and C were selected as 0.38 and 0.16, respectively.

Sludge Production

Biological sludge production data were collected for Breakstone effluent for a period of 4 days. The average biological solids production was 1.0 lbs of dry solids per lb of BOD removed. During the period of observation, the BOD removal of the trickling filter averaged 75%. Generally, low

FIGURE 26

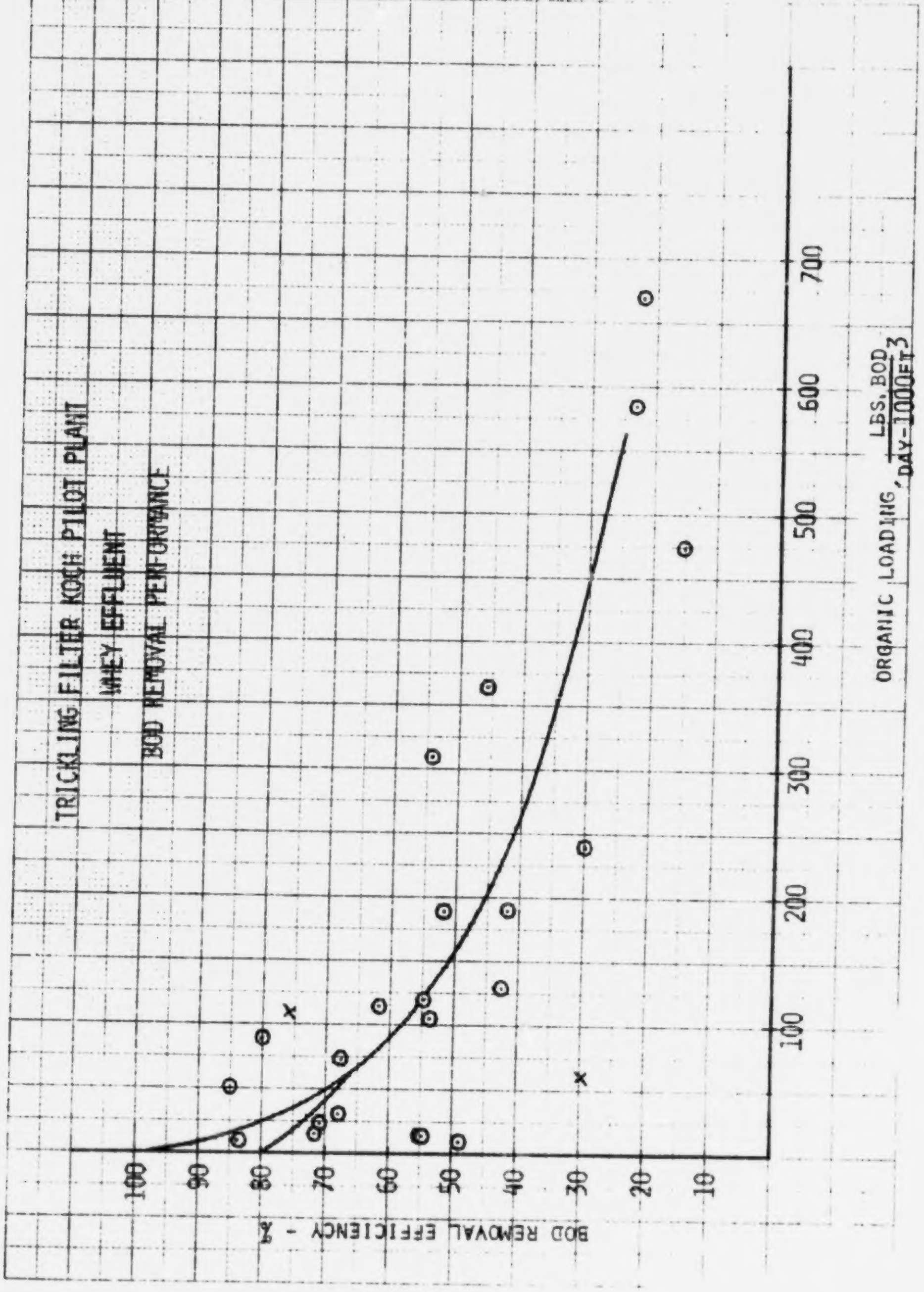
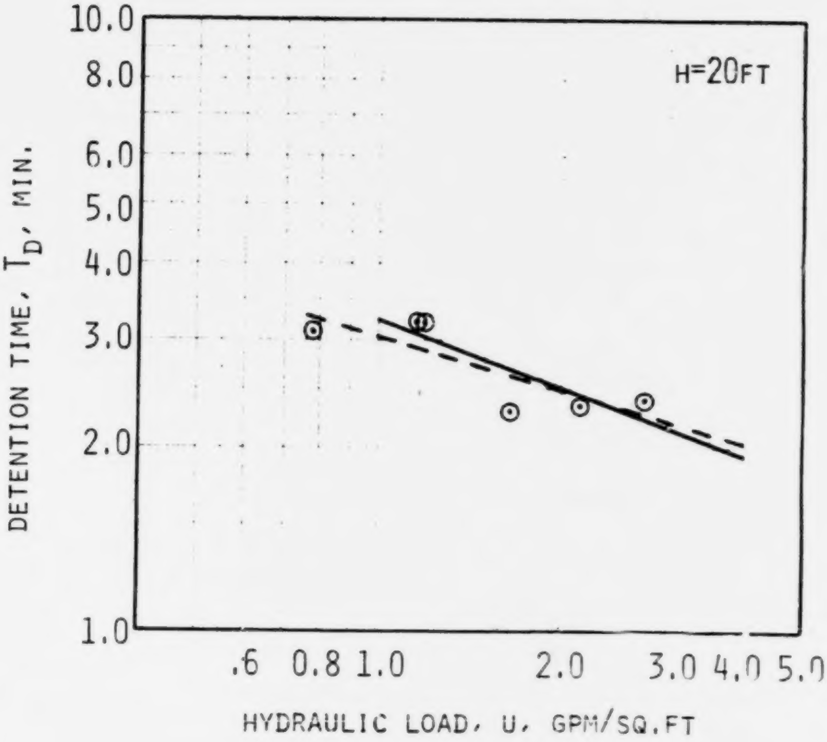

TRICKLING FILTER KOCH PILOT PLANT
WHEY EFFLUENT
BOD REMOVAL PERFORMANCE
BOD REMOVAL EFFICIENCY - %
100
90
80
70
60
50
40
30
20
10
100
200
300
400
500
600
700
ORGANIC LOADING, LBS. BOD / DAY-1000FT3

FIGURE 27

TRICKLING FILTER KOCH PILOT PLANT
WHEY EFFLUENT
DETENTION TIME VS HYDRAULIC LOADING

$$T_D = C_T \frac{H}{U^{N'}}$$



LEGEND

SYMBOL	MINIMUM WETTING RATE	SLOPE N'	C_T
- - - - -	≤ .775	.29	.15
———	≤ 1.17	.38	.16

yields are associated with high degrees of BOD removal (80% to 86%). Lower degrees of removal normally generate higher unit sludge yields. The field studies were not extensive enough for the development of a sludge production model. The unit sludge production for the sewage-Breakstone waste should not differ appreciably from the value observed for the Breakstone effluent. A value of 0.7 lbs of SS per lb of BOD removed is recommended for biological sludge production for Breakstone waste or for the anticipated blend of Breakstone waste with Walton sewage. This value equals the biological yield coefficient for activated sludge treatment as determined from literature data.

Trickling Filter Effluent

The BOD and COD suspended solids equivalent of Breakstone trickling filter effluent were measured during the study. The effluent suspended solids were a combination of Breakstone effluent solids and biological growth. By elimination of the Breakstone effluent suspended solids and their equivalent BOD and COD, an estimation of the BOD and COD equivalents of the biologically produced solids was obtained. These values are .43 lbs of BOD per lb of SS and .94 lbs of COD per lb of SS and approximate the theoretical values expected.

The soluble COD-BOD relationship of Breakstone's treated effluent followed the relationship:

$$\text{BOD} = 0.85[\text{COD}] - 30 \quad \text{................} (\#38)$$

Solids Separation and Compaction

Solids-liquid separation is required to achieve one or more of the following objectives: effluent clarification, sludge thickening, or sludge dewatering.

Effluent Clarification

Effluent clarification is necessary following biological filtration to effect separation of biological growth generated in the process.

The clarification unit serves as an effluent clarifier and a sludge thickener. The thickened sludge (underflow) undergoes further thickening and/or dewatering before disposal.

Measurement of filter effluent clarification of Breakstone waste was made, routinely, by pumping the trickling filter effluent into the holding tanks. When full, the tank was sequentially mixed, sampled, allowed to settle for 30 minutes, and resampled near the surface. The suspended solids removal averaged 79%. This should be considered a limiting value, i.e., attainable at low overflow rates, unless chemicals are used to aid settling. Clarifier underflow is expected to be approximately 1% solids.

Solids Compaction

Sludge thickening devices are used to minimize the sludge volume for further dewatering and ultimate disposal. Gravity thickening is the most common thickening method and the one investigated in this study.

Batch analyses of sludge compaction characteristics, using 1-liter graduated cylinders equipped with a 1/6 rpm stirrer mechanism, were performed for various initial solids concentrations. A batch analysis will provide the means of determining the relationship between sludge compaction and solids loading. The batch relationship may be scaled-up to prototype conditions using experience factors obtained from previous comparisons.

Compaction performance is described in terms of a concentration effect relating the increase achieved in solids concentration to the initial concentration as follows:

$$C_p = \frac{S_y - S_a}{S_a} = \frac{\Delta S}{S_a} \quad \text{..................(\#39)}$$

where:

C_p = compaction performance

S_y = solids concentration in thickener underflow

S_a = solids concentration applied in thickener inflow

ΔS = increase in solids concentration achieved

Concentration performance obtainable in a gravity-thickener will decrease as solids loading to the unit increases. The relationship between compaction performance and solids loading may be expressed, empirically, as follows:

$$C_p = \frac{K_t}{(SL)^{n_t}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\#40)$$

where:

K_t = a thickening constant descriptive of test geometry and initial solids concentration

n_t = a constant descriptive of sludge type

SL = solids loading in lbs/SF/day

The value of n_t is, normally, constant for a given type of sludge solids. The value of K_t, and therefore the thickening characteristics of the sludge, will, however, vary with the initial concentration of solids applied to the thickener.

The dependency of K_t on solids concentrations is formulated using an exponential relationship as follows:

$$\frac{K_t}{K'_t} = (e)^{-n_c S'_a} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (\#41)$$

where:

K'_t = the maximum value of the constant K_t obtained for dilute solids concentration

S'_a = initial solids concentration expressed as ppt, i.e., ppm x 10^{-3}

n_c = a sludge characteristic descriptive of the effects of sludge concentration, i.e., if $n_c = 0$, sludge concentration has no effect on the value of K_t

Compaction tests were performed on selected sludge samples of Breakstone and combined sewage-Breakstone waste. Graphical representations of equations (#40) and (#41) are shown in Figures 28 and 29 for the respective sludges. Table 27 compares the compaction characteristics obtained in this study with those of other effluents.

Thickener design relates solids loading to the compaction performance required and to the effects of initial solids concentration. A quantitative relationship is achieved by combining the preceding equations as follows.

TRICKLING FILTER TREATMENT
WHEY EFFLUENT
EFFECT OF SOLIDS LOADING ON SLUDGE COMPACTION

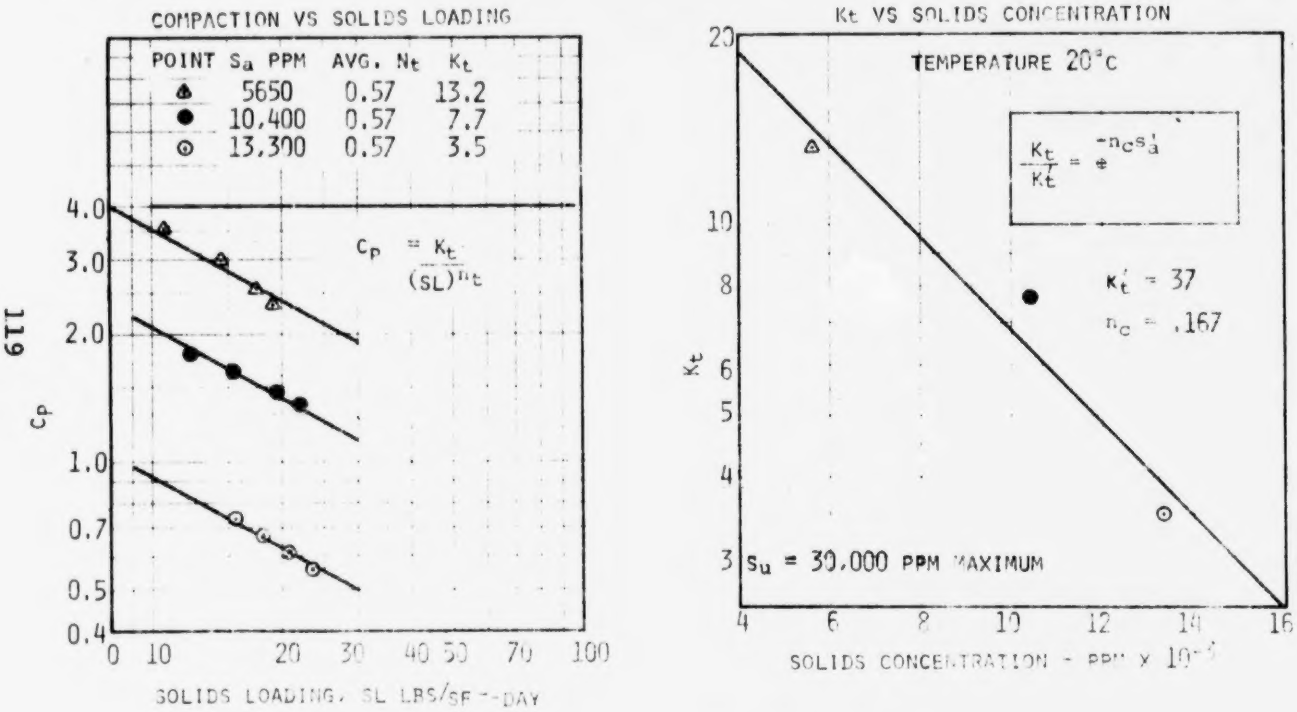


FIGURE 28

TRICKLING FILTER TREATMENT
WHEY & SEWAGE
EFFECT OF SOLIDS LOADING ON SLUDGE COMPACTION

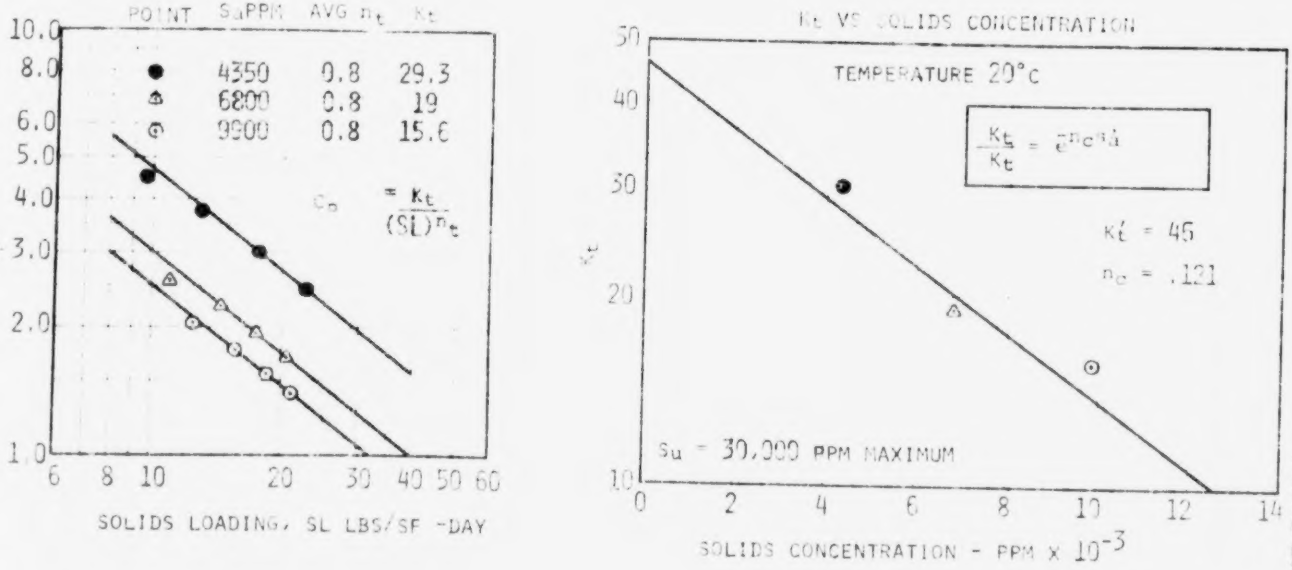


FIGURE 29

TABLE 27

Comparison of Sludge Thickening Characteristics

Sludge Source	Thickener Constants		Concentration Constant
	N_t	K'_t	N_c
1. Sewage	1.05	150	.088
2. Yeast Effluent and Sewage	1.00	350	.270
3. Kraft Effluent	0.56	41	.086
4. Kraft and NSSC Effluent	0.70	115	.220
5. Whey Effluent from Trickling Filtration	0.57	37	.167
6. Whey and Sewage from Trickling Filtration	0.80	46	.121

$$SL = \left[K_t' / C_p \right]^{1/n_t} \left[1/e \left(\frac{n_c}{n_t} \right) (S_a') \right] \text{.........} (\#42)$$

Scale-up to full-scale is achieved from previous comparisons between K_t values obtained for a given batch testing geometry and for prototype condition. A scale-up factor (batch to prototype) of 0.65 for K_t has been shown to apply over a wide range of prototype operation conditions [39].

Solids loading is related to overflow rate by the following material balance:

$$OR = \frac{SL}{S_a} \quad \frac{10^6}{8.34} \text{.....................} (\#43)$$

where:

OR = overflow rate in gal./day/SF

Table 28 presents overflow rates for a range of influent and underflow solids concentrations for both the Breakstone effluent and sewage-Breakstone mixtures. These results demonstrate that the sewage-Breakstone combination exhibited better settling characteristics than those of the Breakstone effluent alone.

TABLE 28

Trickling Filtration Treatment
Whey and Sewage
Sludge Thickener Design

Initial Suspended Solids (ppm)	Overflow Rate (gal./day/SF)		
	Su=20,000	Su=25,000	Su=30,000
7,500	190	125	91
10,000	185	111	78
12,500	192	101	66

Sludge Centrifugation

A centrifuge test of the trickling filter sludge was conducted at the Warminster Laboratory of the Sharples division of the Pennwalt Corporation. Photographs of the centrifuge facility are presented as Figure 30.

The sludge sample used for testing was a composite of sludge collected during two days' operation. During the normal operation, the trickling filter effluent was pumped alternately into two tanks and allowed to settle. The resulting supernatant was pumped out and the remaining concentrated sludge was saved for the centrifuge test. The average time between sludge collection and the centrifuge test was 1.5 days. Ambient air temperatures of 50°F were employed for sample preservation. The average trickling filter operating conditions during the sludge collection and for 5 days preceding were as follows:

Waste - Breakstone Effluent

Hydraulic Loading - 1.1 gpm/SF

Recirculation Ratio - 3.1

BOD Loading - 130 lb/day/1,000 CF

Filter Temperature - 59°F

BOD Removal Efficiency - 51%

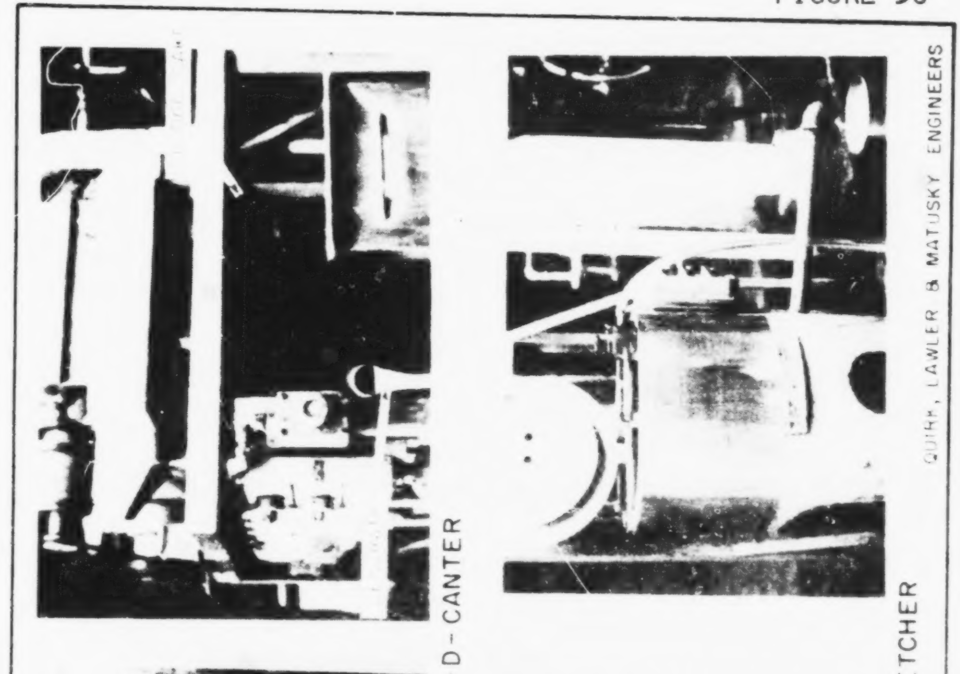
Centrifuge Test Description

A 100-gal. sample of a 0.74% sludge was used for the centrifuge test. Jar tests, for chemical aids, were conducted for a qualitative evaluation of coagulation. Nalco 610 appeared to be the most effective and was selected for evaluation during the centrifuge runs.

Two types of centrifuges were evaluated. The first was the Super-D-Canter P-600, which is a continuously fed, 6-in., horizontal bowl centrifuge. The unit was evaluated at various feed rates without the addition of the chemical aid, and at a selected feed rate with various amounts of chemical aid.

The second centrifuge was a Fletcher Model 2PP-200, which is an automatic, cyclically fed, vertical bowl centrifuge. This

FIGURE 30



SUPER-D-CANTER

FLETCHER

QUIRK, LAWLER & MATUSKY ENGINEERS

unit was evaluated at various feed rates without the addition of the chemical aid. The effect of chemical aid was estimated by assuming the same improvement as that which occurred with the Super-D-Canter. Samples of the centrate liquid and sludge cake were measured for suspended and total solids, respectively.

Centrifuge Test Results

Table 29 presents results for all the centrifuge runs. Interpolation of percent recoveries at common feed rates shows that the Fletcher model had higher recoveries than the Super-D-Canter. The addition of 9.3 lbs of chemical per ton of dry solids at a feed rate of about 19 lbs per minute raised the percent recovery of the Super-D-Canter to the level of the Fletcher model. The cake solids concentration of the Super-D-Canter and the Fletcher were respectively 6% and 9%.

Both models appear to give reasonable feed rates for acceptable recoveries of 80% to 85%. However both models' cake solids concentrations are well below the desired values.

Vacuum Filtration

Laboratory Studies

Rotary vacuum filters are the most popular mechanical devices for the dewatering of waste sludges. The equipment features gentle handling of the sludge during the dewatering operation which enables maximum exploitation of chemical conditioning as a means of improvement of sludge characteristics. Chemicals can be added to the sludge to effect release of water from gels and aggregation of fine particles. The resultant suspension can be dewatered at increased rates if the aggregates are not disrupted by subsequent turbulent transfer operations. Vacuum filters also possess the asset of production of a relatively dry dewatered product.

Limitations associated with vacuum filtration are that biological sludges may undergo structural collapse upon application of a vacuum with concomitant clogging of the filter. Also, relatively skilled operation is required.

Vacuum filtration may be effectively evaluated in the laboratory by specific resistance concepts obtained from Buchner funnel and filter leaf tests. The Buchner funnel

TABLE 29

Trickling Filtration Treatment
Whey and Sewage
Centrifugation of Waste Sludge

Slurry Feed Rate (lbs/min)	Chemical Aid Feed Rate (lbs/ton of Dry Solids)	Super-D-Canter P-600		Fletcher 2PP-200	
		Percent Recovery	Cake Solids, Percent	Percent Recovery	Cake Solids, Percent
2.1	-	-	-	99.2	Average 9%
6.5	-	-	-	99.4	
9.5	-	-	-	93.7	
23.5	-	-	-	77.2	
6.8	-	98.9	5.5	-	
9.9	-	98.7	6.3	-	
18.9	-	59.0	-	-	
23.7	-	59.8	5.7	-	
18.3	9.3	81.7	5.9	-	
19.2	19.6	82.1	-	-	
19.3	33.0	86.7	6.5	-	

test is advantageous for rapid screening of sludge conditioning agents and procedures, whereas the filter leaf provides performance more nearly analogous to prototype rotary vacuum filtration.

The rate of filtration can be described in terms of two resistances in series: the resistance offered by the filter medium and that offered by the cake.

$$\frac{dV}{dt} = \frac{PA^2}{M(rcV + R_m A)} \qquad \text{(\#44)}$$

where:

V = filtrate volume

t = time

P = pressure difference

A = area

M = filtrate viscosity

r = specific resistance

c = sludge solids concentration in filtration process

R_m = unit resistance of filter medium

If the vacuum level is kept constant, the expression can be integrated and rearranged to give the following relation where C is the mean value of sludge solids concentration during the filtration.

$$\frac{t}{V} = \frac{MrCV}{2PA^2} + \frac{MR_m}{PA} \qquad \text{(\#45)}$$

Generally, the resistance of the filter medium is negligible compared to the resistance of the sludge cake - permitting elimination of the second term and direct calculation of specific resistance.

Coakley and Jones proposed the analysis of laboratory filtration results on the basis of specific resistance to obtain unbiased comparison of the filtration characteristics of sludges. The determination of specific resistance is accomplished by filtration of a measured volume of sludge through a Buchner funnel apparatus modified only in that the filtrate receiver is graduated. Readings of filtrate volume are taken at frequent intervals. Specific resistance is calculated from the following equation (assuming negligible resistance through the filtration medium):

$$r = \frac{2bPA^2}{MC} \quad \text{..........................(\#46)}$$

where:

b = experimentally determined constant relating the volume of filtrate to the filtering time

The mean value of sludge solids concentration during filtration may be estimated from the relationship:

$$C = \frac{1}{(1-C_i)/C_i - (1-C_f)/C_f} \quad \text{..........(\#47)}$$

where:

C_i = initial weight of solids per unit volume of sludge, g/ml

C_f = final weight of solids per unit volume of sludge, g/ml

Most waste sludges of biological origin form compressible cakes in which the filtration rate and the specific resistance are functions of the pressure difference across the cake. The effect of pressure difference on the specific resistance of such sludges can be described by the following reaction:

$$r = r_{\circ}P^s \quad \text{...........................(\#48)}$$

where:

$\circ$ = specific resistance at unit pressure

r = specific resistance

P = pressure difference

s = coefficient of compressibility

The effect of sludge compressibility on specific resistance was determined. Measurement of specific resistance versus pressure (Figure 31) resulted in a coefficient of compressibility of .91. The high coefficient of compressibility implied that filtration rate was relatively independent of pressure difference. For this reason, a moderate vacuum pressure of 12 in. Hg was selected for leaf test and design conditions.

Specific resistance was used to select a chemical conditioner and its optimum dosage. The three conditioners evaluated were: ferric chloride, a Dow Chemical Company polymer Purifloc C-31, and lime addition in conjunction with ferric chloride. Figure 32 presents a comparison of ferric chloride with Purifloc C-31. The two conditioners were compared using dosages of comparable cost. The results favored the use of ferric chloride rather than the polymer. In addition to the above tests, various dosages of lime in conjunction with a constant dosage of ferric chloride were evaluated. Specific resistance was found to increase as lime was added to the samples. For this reason, lime was eliminated from consideration and ferric chloride was selected as the conditioner for further tests and final design.

The determination of the optimum dosage of ferric chloride was made by measuring specific resistance versus dosage on three representative samples. Figure 33 illustrates the results of these tests. The figure indicates that regardless of the initial value of specific resistance, the values after the optimum chemical addition were approximately the same. From this figure, 7 lbs of ferric chloride per 100 lbs of suspended solids was selected as the optimum dosage.

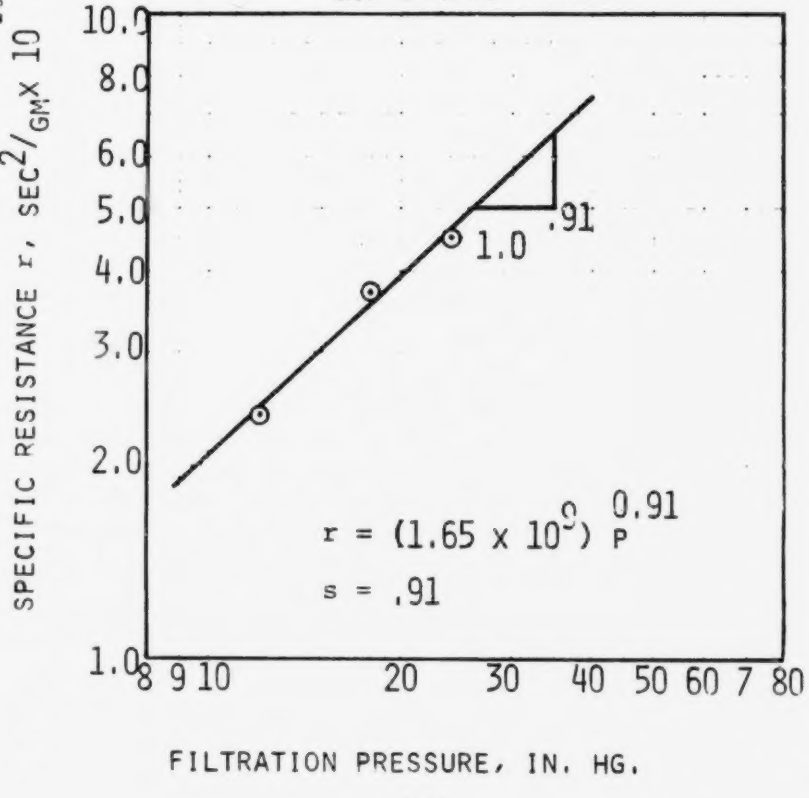
Leaf Testing

Vacuum filter solids loading rates were determined by performing a series of filter leaf tests on a selected sludge sample. Table 30 presents a summary of test conditions and results. The ferric chloride dosage used in runs 5 and 6 was less than the optimum dosage previously indicated. This resulted from an initial solids concentration that was higher than estimated. Design of filter loadings from these tests will provide a margin of safety by which higher chemical dosages can be used to increase filter capacity.

FIGURE 31

TRICKLING FILTER TREATMENT
WHEY EFFLUENT

SPECIFIC RESISTANCE
VS
FILTRATION PRESSURE
(NO CONDITIONING)



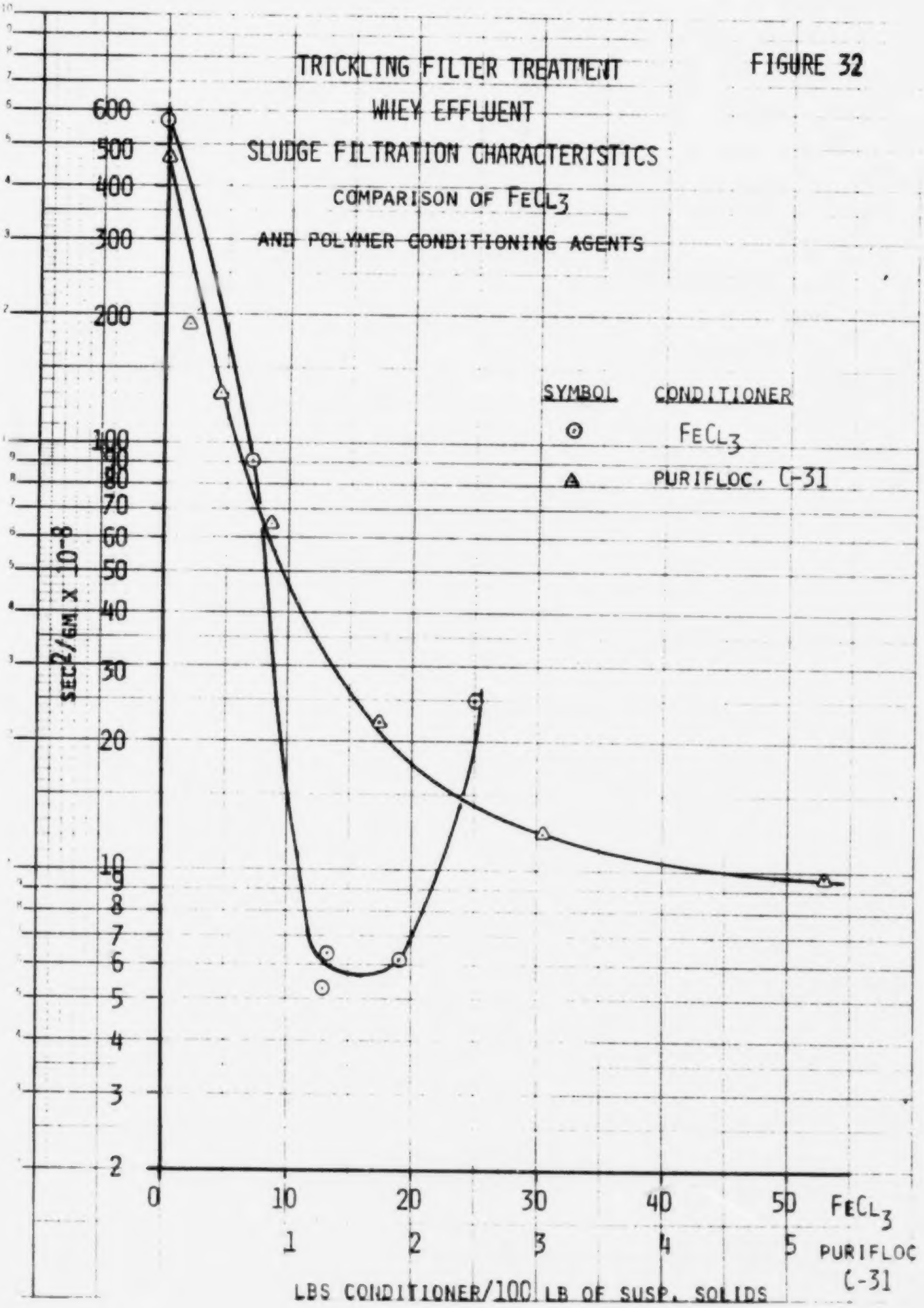


FIGURE 32

TRICKLING FILTER TREATMENT

WHEY EFFLUENT

SLUDGE FILTRATION CHARACTERISTICS

COMPARISON OF $FeCl_3$

AND POLYMER CONDITIONING AGENTS

FIGURE 33

TRICKLING FILTER TREATMENT
WHEY EFFLUENT
SLUDGE FILTRATION CHARACTERISTICS

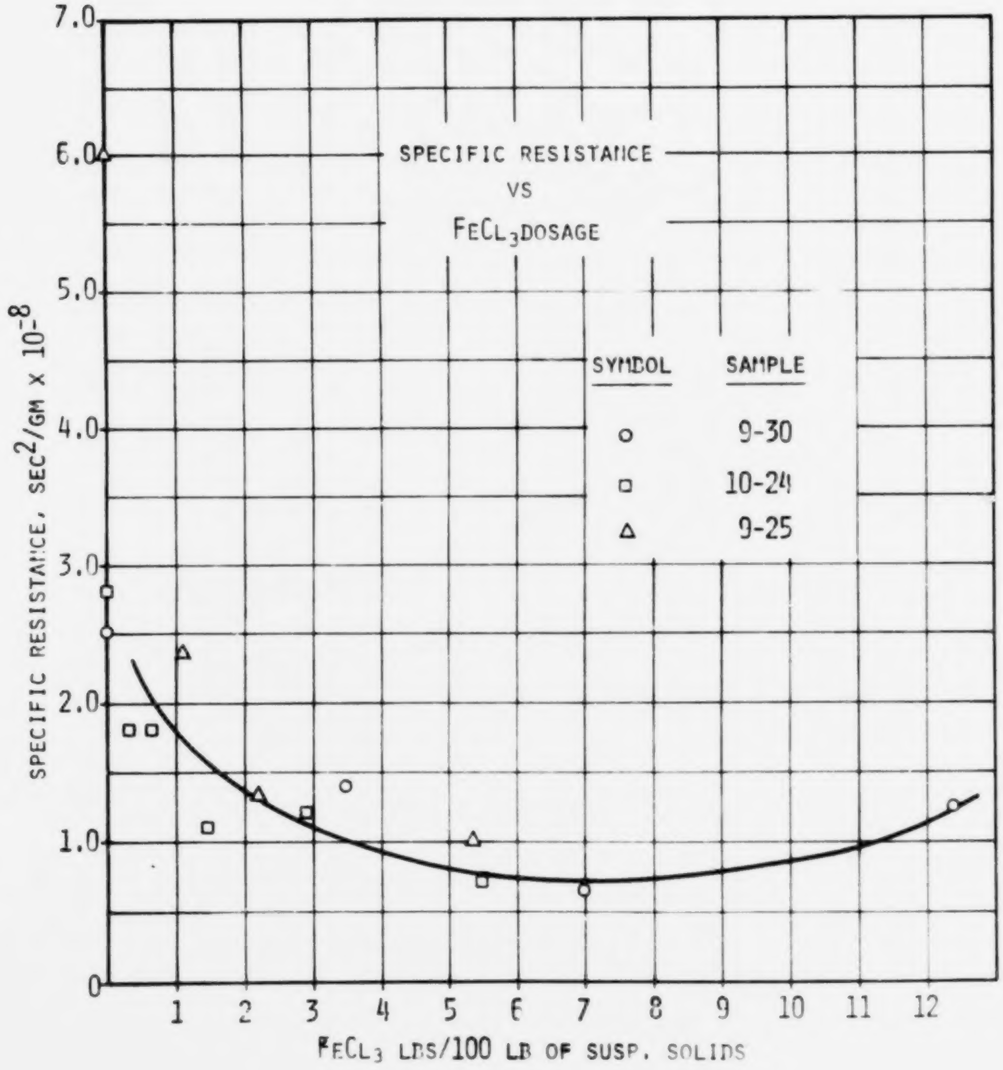


TABLE 30

Trickling Filtration Treatment
Whey and Sewage
Vacuum Filtration of Waste Sludge

(Pressure 12 in. Hg)

Run No.	Form Time t_f (min)	Loading (gm/SF)	Dry Time t_d (min)	Cycle Time t_c (min) w/15% Dead Time	Solids Loading Rate (lbs/SF/hr)	Initial Percent Solids	Sludge Cake Percent Solids	Chemical Conditioning
1	0.5	25.5	1.0	1.77	1.90	2.06	25.2	None
2	1.0	37.4	2.0	3.54	1.40	2.06	20.4	None
3	2.0	43.4	4.0	7.10	0.80	2.06	20.7	None
4	3.0	46.6	6.0	10.6	0.58	2.06	23.8	None
5	1.0	5.8	2.0	3.54	2.16	4.02	21.7	2.5% $FeCl_3$
6	2.0	7.9	4.0	7.10	1.47	4.02	20.6	2.5% $FeCl_3$

Design of a vacuum filter from the above leaf test data requires a modification of the presented loading rates to account for the following design conditions:

1. A manufacturer's recommended cycle time of about 4 minutes
2. A vacuum filter dead time of 15%, i.e., no vacuum on this portion of the filter
3. A manufacturer's recommended effective submergence, or form time, of 25%
4. A reduction of leaf test loading rates by 20% based on manufacturer's experience with previous leaf test and full-scale comparisons
5. A difference in initial solids concentration between test and full-scale application.

Design Calculations for Vacuum Filtration

A cycle time of 4 minutes and a 25% effective submergence results in a form time of 1 minute. Run 5 of Table 30 indicated a solids loading of 5.8 gm/SF for this form time. Using this loading, a cycle time of 4 minutes and a scale-up factor of 80%, the solids loading rate is initially computed to be 1.5 lb/SF/hr.

A modification of the initial loading rate is made for the parameter C given in equation (#44). The value of C for design conditions is 61% lower than the value that occurred during the leaf tests. Raising this factor to one-half power reduces the loading rate to 78% of the test loading. The final value of filter loading rate is computed to be 1.2 lbs/SF/hr.

Cake solids concentration is estimated by comparing the drying time of the test with the design conditions. The drying time for design is obtained by subtracting the form and dead time from the cycle time. This results in a drying time of 2.4 minutes. Run 5 provided a 21.7% cake with 2.0 minutes drying time. Design conditions should yield a cake dryness of 22% or greater.

The vacuum filter design is summarized as follows:

1. Cycle time, 4 min
2. Effective submergence, 25%
3. Loading rate, 1.2 lbs of solid per SF per hr
4. Vacuum pressure, 12 in. Hg
5. Cake solids concentration, 20%-25%
6. Chemical dosage, 7 lbs $FeCl_3$ per 100 lbs of dry solids.

SECTION VII

DISCUSSION

The study work reported herein was undertaken as an outgrowth of a proposal titled "Dynamic Process Development for Biological Treatment of Whey Bearing Wastes" submitted to the WQO, EPA. The proposal envisioned the application of frequency response techniques to activated sludge in an effort to develop a stable system having satisfactory sludge separation characteristics; additionally, investigations were to be made into the applicability of sheet-media packed tower trickling filters to whey-bearing waste treatment. The study had the dual objectives of research into the problem area of whey waste treatment, as documented by other works; and development of a prototype process design and cost estimate for a specific whey waste treatment problem existing in the Village of Walton, New York.

As required by the grant offer, an outline of the proposed work was submitted to the Project Officer (and to all interested parties) prior to commencement of the study. During a subsequent review meeting, a plan was developed wherein packed tower filters equipment and field pilot would start the program. Information from the initial experiment could be compared with activated sludge laboratory work already done on the whey-bearing waste in a previous assignment for the Village of Walton.

Project Scope Modification

The original program anticipated active participation in several study phases by the State of New York Department of Health and Breakstone Sugar Creek Foods Division of Kraftco Corporation. Breakstone Sugar Creek Foods was able to provide a pilot plant site for the erection of a packed tower early in the study. However, the NYSDH was not able to cover operations of the field pilot nor supply laboratory assistance in staffing an activated sludge experiment. Eventually, the delays in reaching a decision regarding State personnel resulted in the transference of personnel and budget allocations to cover the ongoing program needs. The successful operation of a stable filtration system, based on laboratory experiments using plastic-sheet media, encouraged the continuation of these experiments. Emphasis of the packed tower experiments and the inability of the NYSDH

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to react to the original program resulted in modification of the original study outline to minimize the activated sludge system investigations.

Project Budget and Cost Participation

The proposal for the study presented a detailed budget totaling $80,347. The WQO, EPA estimated that $80,047 of the proposed budget would be eligible for Federal participation and a grant offer was made for $52,730. The offer was accepted by the Village of Walton.

Trickling Filtration of Whey Effluent

Trickling filtration of whey effluent and whey effluent mixed with sewage has been shown to be an effective treatment method both on absolute terms and on a relative basis when compared with activated sludge.

A comparison of whey treatability with that of other industrial effluents demonstrates that whey treatability exceeds that of the average industrial effluent when packed tower trickling filters are employed.

Nutrient additions other than ammonia nitrogen were not productive of increased rates of biodegradability. The addition of ferrous iron did not, as anticipated by other investigators, result in an increased treatability.

The inherently acidic reaction of a whey effluent was shown to have no adverse effect on trickling filtration performance using high porosity media. pH variations from 7.0 to 4.5 were not detrimental but, rather resulted in an increase of BOD removal rate as pH decreased. pH increases above 7.0 were shown to result in a reduction of BOD removal rate. Although these comments are based on limited data, the trend of pH influence appears clear. pH variations in a prototype plant are not anticipated to be detrimental to packed tower trickling filter performance.

Trickling filter operating variables of temperature, recirculation and hydraulic application rate have been quantified in a verified, process design model presented in the report. While the number of implications which can be drawn from a detailed sensitivity analysis of the model are too extensive to be within the scope of this study, several qualitative comments can be made as follows. Increased temperatures are beneficial for process performance. Recirculation should be included only to insure adequate application velocities and not to provide additional removal efficiency. The inclusion of recirculation will require provision for additional filter volumes which will normally outweigh the effects of repeated application. The need to maintain application velocities sufficiently high to insure adequate wetting of packing media will require towers of maximum practicable height or stage treatment to provide high BOD removals, economically. This latter requirement is dictated by media characteristics rather than whey characteristics.

Trickling filter performance will be sensitive to flow variation rather than BOD variation. Response times of from 6 to 24 hours should be experienced after a significant change in hydraulic application rate. Under normal operating conditions, filter performance should be stable.

Filter sludge growth will be prolific and will require a high porosity media of low susceptibility to retention of sloughed filter slime to avoid plugging. An open media similar to Surfpac is appropriate.

Sludge growth should be comparable to that quantity experienced by activated sludge.

Filter odors should not be offensive at organic loadings requested for high BOD removals. However, filter installation should be provided with covers if proximate to odor-sensitive areas.

Final sedimentation of filter effluent may require coagulation for production of a low solids effluent and/or for removal of suspended BOD to insure an overall plant performance above 90% BOD removal.

Secondary sludge can be thickened using gravity equipment; however, thickener requirements will be significantly greater than that used for domestic sewage.

Dewatering of secondary sludge can be accomplished by vacuum filtration. Centrifugation performance would be poor and would not be recommended. Vacuum filtration characteristics of trickling filter sludge exceed, significantly, those of activated sludge. Dewatering may well control the selection of the BOD removal process.

Laboratory Treatment Methods

A verified simulation method for analyses and scale-up of trickling filters is not currently available in the engineering literature.

Such a procedure has been recently developed and extended in this study.

Equipment requirements are comparatively simple and operating time can be reduced to requirements less than those for activated sludge.

Scale-up procedures to full-scale design are presented and employed for detailed sizing of treatment units.

Application of these procedures to the study undertaken has demonstrated the utility of the technique.

The procedure is applicable to other industrial effluents and can be utilized by industrial personnel to determine the treatability of individual effluents.

Analyses and Scale-Up of Laboratory Data

In order to effectively utilize laboratory treatment, techniques must be capable of analysis in terms of practical design parameters and must be susceptible to scale-up to full-scale conditions using logically supported procedures which can be readily verified.

Computer programming is employed to accept laboratory data as input and to: produce a tabulation of correlation parameters for alternative kinetic models, perform the graphical correlation required in a particular kinetic model, and compute the reaction rate constants for BOD removals.

The laboratory rate constant can be scaled up to full-scale tower values using the geometric and hydraulic characteristics of the packing media. A comparison between rate constants developed by analysis of full-scale data and by scale-up computations indicates a close comparison.

Full-Scale Packed Tower Process Design

The utility of projects information is completed when the laboratory data have been analyzed, a kinetic model has been selected, scale-up and media selection has been completed, and alternative process designs have been defined in sufficient detail to allow a final design selection.

The report presents a detailed quantitative development of the process design procedures involved in defining alternative designs, including a numerical example for a specific situation.

In addition, computer programming has been employed to accept waste loadings treatment required, and reaction rate as input and to output tabulations of alternative process designs for designer selection.

Cost for Treatment

A detailed capital and operating cost estimate has been prepared for packed tower trickling filtration of whey effluent in combination with a relatively small contribution of domestic sewage.

The estimates have been prepared on a unit operation base and provide a convenient basis for evaluation of the component costs of whey treatment.

Additionally, the detailed rate structure for assigning the capital and operating costs to each of the major waste loading parameters involved in sizing waste treatment facilities was made. This procedure results in a unit cost for each waste loading and provides a guideline for assessment of the relative economies of in-plant modifications to reduce effluent loadings.

SECTION VIII

ACKNOWLEDGEMENTS

Recognition is in order for the technical and financial support needed to make possible an investigation of the scope reported herein. Though it is not possible to identify each separate contribution, mention shall be made of the important financial role of the Environmental Protection Agency, Industrial Pollution Control Program under the direction of William J. Lacy and Mr. H. George Keeler manager, and the technical awareness of their staff members.

Appreciation is given to the late Mr. Hayse H. Black of the State of New York Department of Health, for his interest and encouragement; to Mr. Herbert F. Marston, President of Breakstone Sugar Creek Foods Division of Kraftco Corporation, for his desire to provide a proper solution to a pressing problem; and to Mayor Clifford L. Dennis and the Board of Trustees, Village of Walton, New York, for undertaking the responsibility of authorizing this investigation.

The study outline was initially prepared by Dr. William A. Parsons, formerly of Quirk, Lawler & Matusky Engineers; its development and execution were under the direction of Mr. Thomas P. Quirk.

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SECTION IX

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SECTION X

GLOSSARY

Abbreviations

BOD = Biochemical Oxygen Demand

BOD_5 = Biochemical Oxygen Demand after 5 days incubation at 20°C

COD = Chemical Oxygen Demand

°C = degrees Centigrade

CF = cubic feet

$FeCl_3$ = ferric chloride

Fe = ferrous iron

ft = feet

gal. = gallon

gm = gram

gpm = gallons per minute

gpd = gallons per day

HG = mercury

hr = hour

in. = inch

l = liter

lbs = pounds

LF = linear feet

mg = million gallons

mgd = million gallons per day

mg/L = milligram per liter

min = minute

mL = milliliter

N = nitrogen

NaOH = sodium hydroxide

OR = overflow rate expressed in dimensions of gallons per day per square foot

ppm = parts per million

sec^2 = seconds squared

SF = square feet

SVI = sludge volume index

° = degrees

% = percent

Mathematical Typography

A_s = area of slime

A_v' = area of wetted surface area of media in trickling filter expressed in dimensions of square feet per cubic foot of filter volume

A_v'' = area of slime surface in trickling filter expressed in dimensions of square feet per cubic foot of filter volume

A_v = area of dry surface area of trickling filter packing media per cubic foot of filter volume

A = area

b = a constant of integration

C = a constant

C_p = a coefficient of performance for gravity compaction

C_i = initial sludge solids concentration in filtration process

C_f = final sludge solids concentration in filtration process

C_s = sludge solids concentration in filtration process

C_w = a constant equal to the ratio of wetted media to total media area in a trickling filter

d = depth of liquid flowing over a slimed surface

dH = a differential element of height

dL = a differential change in concentration

DV_r = a differential segment of volume of a BOD removal reactor

e = the naperien base 2.718

E = efficiency of untreated BOD removal

f = a factor representing the ratio L_o/L_e

F = Fahrenheit temperature

f_t = a factor equal to the ratio of surface area of slime to surface area of media supporting slime growth

f_w = a factor applied to slime area to obtain weight of surface slime effective in obtaining BOD removal from flowing liquid

H = height of slimed surface and length of slimed surface for non-vertical geometrics

k, k', k'' = a specific biological rate constant for BOD removal

K_{20} = a BOD removal rate constant for a specific effluent and a specific trickling filter packing media expressed at a standard reference temperature of 80°C in the dimensions of gallons per minute per cubic foot

k_{20}, k'_{20} = a specific biological rate constant at a standard reference temperature of 20°C

K_r = a general BOD removal rate expressed in dimensions of concentration change per unit of time

k_t, k'_t, k''_t = a specific biological rate constant at a given temperature t

K'_t = the maximum value of the constant K_t

K_t = a constant descriptive of gravity thickening characteristics obtained for given geometry of thickening system and for given solids applied to thickener

L = concentration expressed in dimensions of weight per unit volume

L_a = BOD concentration applied to trickling filter excluding diluting effects of recirculation expressed in dimensions of weight per unit volume

L_e = BOD concentration as effluent from slimed surface

L_o = BOD concentration as fed to slimed surface including effects of recirculation

L'_r = BOD concentration removed by trickling filter including the dilution effects of recirculation expressed in dimensions of weight per unit volume

n = a constant

n_c = a gravity thickening constant descriptive of the effects of applied solids concentration on thickening characteristics

n_t = a gravity thickening constant descriptive of sludge type

OL = organic loading to trickling filter expressed in units of weight of BOD per unit of time per unit of trickling filter volume

P = pressure differential during vacuum filtration process

Q = untreated waste flow rate

R = treated waste flow rate recirculated through trickling filter

r = recirculation ratio equal to the ratio R/Q

r_s = specific resistance of solids being filtered

R_m = unit resistance of filtering medium in vacuum filtration process

r_o = specific resistance of solids being filtered at unit pressure differential

S = concentration of organisms in dimensions of weight per unit volume

s = a constant descriptive of solids compressibility

ΔS = change in solids concentration achieved in thickener

S_a = solids concentration applied to thickener in inflow

S'_a = $S_a \times 1/1000$

SL = solids loading in dimensions of pounds per square foot per day

S_u = solids concentration in underflow from gravity thickener

t = elapsed time

ΔT = a temperature differential from 20°C

U = a flow rate including recirculation, if any, per unit of cross sectional area of media filled trickling filter

U' = a flow rate, including recirculation, if any, per unit width of slimed surface

u = filtrate viscosity

U_o = a flow rate per unit of cross sectional area of a media filled trickling filter when recirculation is not employed

U_{min} = a minimum flow rate, including recirculation, if any, per unit of cross sectional area of a media filled trickling filter

V = volume of filtrate obtained during vacuum filtration process

V' = volume of trickling filter per unit of flow of untreated waste flow

V'_o = volume of a non-recirculated trickling filter per unit of flow of untreated waste flow

θ = a constant

° = degrees

" = inches

APPENDIX

INCLINED PLANE FIRST ORDER REACTION

```
WXQT

     WHEY BEARING WASTE STUDY   179-0

            PLANE LENGTH =  9.00 FT.

            PLANE WIDTH =  .50 IN.

        ANGLE OF PLANE WITH HORIZON = 45.0 DEG.

            SLIME AREA =  .375 SF.

 NO.   LA      LO      LE      E        R                  Q              R/Q     F     THEORE.      TEMP.       REMARKS
                                                                                        DET.TIME
      (PPM)   (PPM)   (PPM)        (ML/MIN) (GPM)  (ML/MIN) (GPM)                        (SEC)     (F)   (C)

  1   570.0   451.2  380.0   .333   11.0   .0029     6.6   .0017   1.67  1.187     24.8      78.0  25.6
  2   570.0   509.5  440.0   .228   10.4   .0028    12.0   .0032    .87  1.158     20.9      80.0  26.7
  3   570.0   244.9  180.0   .684   11.2   .0030     2.2   .0006   5.01  1.361     29.2      82.0  27.8
  4   490.0   432.6  380.0   .224   12.0   .0032    11.0   .0029   1.09  1.138     20.4      81.0  27.2
  5   490.0   272.3  220.0   .551   10.0   .0026     2.4   .0006   4.17  1.238     30.7      82.0  27.8
  6   490.0   181.3  135.0   .724   10.0   .0026     1.5   .0004   6.67  1.343     32.4      81.0  27.2
  7   720.0   513.3  410.0   .431   10.0   .0026     5.0   .0013   2.00  1.252     28.4      70.0  21.1
  8   670.0   570.0  510.0   .239   10.0   .0026     6.0   .0016   1.67  1.118     26.6      76.0  24.4
  9   720.0   473.0  370.0   .486   11.0   .0029     4.6   .0012   2.40  1.278     27.1      76.0  24.4
 10   600.0   399.2  310.0   .483    9.0   .0024     4.0   .0011   2.25  1.288     30.5      76.0  24.4
 11   550.0   396.7  320.0   .418   10.0   .0026     5.0   .0013   2.00  1.240     27.1      82.0  27.8
 12   560.0   473.3  430.0   .232   10.0   .0026     5.0   .0013   2.00  1.101     26.7      85.0  29.4
 13   640.0   365.0  240.0   .625   11.0   .0029     5.0   .0013   2.20  1.521     25.6      85.0  29.4
 14   480.0   264.5  170.0   .646   10.0   .0026     4.4   .0012   2.28  1.556     27.4      85.0  29.4
 15   540.0   540.0  220.0   .593     .0   .0000     3.7   .0010    .00  2.455     67.2      87.0  30.6
 16   540.0   540.0  330.0   .389     .0   .0000     6.1   .0016    .00  1.636     49.3      82.0  27.8
 17   270.0   270.0  230.0   .149     .0   .0000    13.5   .0036    .00  1.174     28.4      87.0  30.6
 18   270.0   270.0  125.0   .537     .0   .0000     3.0   .0008    .00  2.160     78.4      84.0  28.9
 19   510.0   510.0  190.0   .627     .0   .0000     3.6   .0010    .00  2.684     68.5      87.0  30.6
```

FIRST ORDER CORRELATION PARAMETERS

LET TF = TEMP. CORRECTION FACTOR

NO.	U (GPM/FT)	U (ML/MIN/IN)	TF	F	LOGF	H.TF/U (SQ.FT/GPM)	H.TF/LOGF (FT)	LOG(H.TF/LOGF)	LOGU	REMARKS
1	.112	35.2	1.211	1.187	.0746	97.63	145.00	2.1643	-.9523	
2	.142	44.8	1.258	1.158	.0637	79.70	177.67	2.2496	-.8476	
3	.085	26.8	1.307	1.361	.1337	138.42	87.95	1.9442	-1.0707	
4	.146	46.0	1.282	1.138	.0563	79.12	204.00	2.3115	-.8361	
5	.079	24.8	1.307	1.238	.0926	149.58	127.07	2.1040	-1.1044	
6	.073	23.0	1.282	1.343	.1281	158.23	90.09	1.9547	-1.1372	
7	.095	30.0	1.039	1.252	.0976	98.31	95.79	1.9813	-1.0218	
8	.101	32.0	1.165	1.118	.0483	103.37	217.10	2.3367	-.9937	
9	.099	31.2	1.165	1.278	.1066	106.02	98.34	1.9927	-1.0047	
10	.082	26.0	1.165	1.288	.1099	127.22	95.45	1.9798	-1.0839	
11	.095	30.0	1.307	1.240	.0933	123.65	126.09	2.1007	-1.0218	
12	.095	30.0	1.384	1.101	.0417	130.95	298.69	2.4752	-1.0218	
13	.101	32.0	1.384	1.521	.1821	122.77	68.40	1.8351	-.9937	
14	.091	28.8	1.384	1.556	.1920	136.41	64.87	1.8121	-1.0395	
15	.023	7.4	1.438	2.455	.3000	551.57	33.18	1.5209	-1.6297	
16	.039	12.2	1.307	1.636	.2139	304.07	54.09	1.7403	-1.4125	
17	.086	27.0	1.438	1.174	.0696	151.17	185.83	2.2691	-1.0675	
18	.019	6.0	1.358	2.160	.3345	642.36	36.54	1.5627	-1.7207	
19	.023	7.2	1.438	2.684	.4288	566.89	30.18	1.4797	-1.6416	

APPENDIX

INCLINED PLANE SAMPLE RETARDENT ANALYSIS

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PXQT
    WHEY BEARING WASTE STUDY   179-C

          PLANE LENGTH = 18.00 FT.
          PLANE WIDTH =  .50 IN.
      ANGLE OF PLANE WITH HORIZON = 30.0 DEG.
          SLIME AREA =  .750 SF.

 NO.   LA      LO      LE      E        R                 Q            R/Q     F     THEORE.      TEMP.        REMARKS
                                                                                      DET.TIME
      (PPM)   (PPM)   (PPM)         (ML/MIN) (GPM) (ML/MIN) (GPM)                     (SEC)     (F)   (C)
  1   550.0   950.0  140.0   .749     .0   .0000     3.8   .0010     .00  3.929    155.8     76.0  24.4
  2   550.0   550.0  160.0   .709     .0   .0000     3.6   .0010     .00  3.438    166.7     68.0  20.0
  3   380.0   380.0  110.0   .711     .0   .0000     3.9   .0010     .00  3.455    151.1     79.0  26.1
  4   400.0   400.0   80.0   .800     .0   .0000     3.8   .0010     .00  5.000    156.4     75.0  23.9
  5   390.0   179.0   85.0   .782    8.3   .0022     3.7   .0010    2.24  2.106     73.5     72.0  22.2
  6   390.0   390.0   26.0   .933     .0   .0000     4.2   .0011     .00 15.000    142.0     82.0  27.8

  SIMPLE RETARDANT CORRELATION PARAMETERS

         LET  TF = TEMP. CORRECTION FACTOR

 NO.          U                 TF      F       H.TF/U          REMARKS
    (GPM/FT) (ML/MIN/IN)                     (SQ.FT/GPM)

  1     .024        7.6      1.165  3.929     870.45
  2     .023        7.2      1.000  3.438     788.54
  3     .025        7.8      1.234  3.455     898.18
  4     .024        7.6      1.143  5.000     853.97
  5     .076       24.0      1.079  2.106     255.36
  6     .027        8.4      1.307 15.000     883.24
```

APPENDIX

TRICKLING FILTER DESIGN OUTPUT

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                 KINETIC MODELS TO EXPLAIN BOD REMOVAL FOR
                      PACKED TOWER TRICKLING FILTER


GENERAL DESIGN CRITERIA...
        BOD REMOVAL RATE AT 20 C                            .03000
        ACTUAL TEMPERATURE                                    22.0 C
        TEMPERATURE CORRECTION FACTOR (THETA)               1.0350
        BOD REMOVAL RATE AT ACTUAL TEMPERATURE              .03214
        TOTAL WASTE TO BE TREATED (FLOW)                     694.4 G.P.M.
        TOTAL WASTE TO BE TREATED (BOD)                     1800.0 LBS/DAY
        MINIMUM APPLICATION RATE                              1.00 G.P.M./SQ.FT.
        DEPTH OF TOWER                                        21.0 FEET
        "N" VALUE OF MEDIA CHOSEN                            1.000
        TOTAL REMOVAL EFFICIENCY REQUIRED                    95.00 %


                 KINETIC MODEL CHOSEN WAS FIRST ORDER
                 UNITS WERE SIZED ASSUMING 1,2,AND 3 STAGES


                               SINGLE STAGE   TWO STAGE      THREE STAGE

EFFICIENCY / STAGE (%)             95.00          77.64          63.08
APPLICATION RATE (GPM/SQ FT)        .226           .451           .678
RECIRCULATION RAYIO                 .000           .000           .000
VOLUME / STAGE (CU.FT.)          64658.1        32329.0        21507.3
STAGE VOLUME/ RAW FLOW,CF/GPM      93.11          46.56          30.97
TOTAL VOLUME (CUBIC FFET)        64658.1        64658.1        64522.0
NOMINAL FLOW PUMPED PER STAGE      694.4          694.4          694.4
TOTAL NOMINAL FLOW PUMPED          694.4         1388.8         2083.2
NUMBER OF PUMPING STATIONS             1              2              3


ORGANIC LOADINGS TO FILTER

   FOR 1 STAGE FILTRATION...
        ORGANIC LOAD TO FIRST FILTER                   27.839 LBS/DAY--1000CF

                         PARALLEL FILTERS          DIAMETER
                         PER STAGE                 PER STAGE
                                  1                     62.6 FEET
                                  2                     44.3 FEET
                                  3                     36.2 FEET
                                  4                     31.3 FEET

   FOR 2 STAGE FILTRATION...
        ORGANIC LOAD TO FIRST FILTER                   55.677 LBS/DAY--1000CF
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     ORGANIC LOAD TO SECOND FILTER                   12.450 LBS/DAY--1000CF

                              PARALLEL FILTERS        DIAMETER
                              PER STAGE               PER STAGE
                                         1                 44.3 FEET
                                         2                 31.3 FEET
                                         3                 25.6 FEET
                                         4                 22.1 FEET
  FOR 3 STAGE FILTRATION...
     ORGANIC LOAD TO FIRST FILTER                    83.692 LBS/DAY--1000CF
     ORGANIC LOAD TO SECOND FILTER                   30.897 LBS/DAY--1000CF
     ORGANIC LOAD TO THIRD FILTER                    11.407 LBS/DAY--1000CF

                              PARALLEL FILTERS        DIAMETER
                              PER STAGE               PER STAGE
                                         1                 36.1 FEET
                                         2                 25.5 FEET
                                         3                 20.9 FEET
                                         4                 18.1 FEET


                              SINGLE STAGE   TWO STAGE       THREE STAGE

EFFICIENCY / STAGE (%)              95.00         77.64           63.08
APPLICATION RATE (GPM/SQ FT)        1.000         1.000           1.000
RECIRCULATION RATIO                18.714         2.603            .773
VOLUME / STAGE (CU.FT.)          287477.7       52534.8         25853.6
STAGE VOLUME/ RAW FLOW,CF/GPM      413.99         75.65           37.23
TOTAL VOLUME (CUBIC FEET)        287477.7      105069.7         77560.4
NOMINAL FLOW PUMPED PER STAGE     13689.4        2501.7          1231.1
TOTAL NOMINAL FLOW PUMPED         13689.4        5003.3          3693.4
NUMBER OF PUMPING STATIONS              1             2               3


ORGANIC LOADINGS TO FILTER

  FOR 1 STAGE FILTRATION...
     ORGANIC LOAD TO FIRST FILTER                     6.261 LBS/DAY--1000CF

                              PARALLEL FILTERS        DIAMETER
                              PER STAGE               PER STAGE
                                         1                132.1 FEET
                                         2                 93.4 FEET
                                         3                 76.2 FEET
                                         4                 66.0 FEET

  FOR 2 STAGE FILTRATION...
     ORGANIC LOAD TO FIRST FILTER                    34.263 LBS/DAY--1000CF
     ORGANIC LOAD TO SECOND FILTER                    7.661 LBS/DAY--1000CF

                              PARALLEL FILTERS        DIAMETER
                              PER STAGE               PER STAGE
                                         1                 56.5 FEET
                                         2                 39.9 FEET
```

```
                                        3                     32.6 FEET
                                        4                     28.2 FEET
  FOR 3 STAGE FILTRATION...
       ORGANIC LOAD TO FIRST FILTER                     69.623 LBS/DAY--1000CF
       ORGANIC LOAD TO SECOND FILTER                    25.703 LBS/DAY--1000CF
       ORGANIC LOAD TO THIRD FILTER                      9.489 LBS/DAY--1000CF

                           PARALLEL FILTERS             DIAMETER
                           PER STAGE                    PER STAGE
                                        1                     39.6 FEET
                                        2                     28.0 FEET
                                        3                     22.9 FEET
                                        4                     19.8 FEET
GENERAL DESIGN CRITERIA...
       BOD REMOVAL RATE AT 20 C                         .03214
       ACTUAL TEMPERATURE                                 22.0 C
       TEMPERATURE CORRECTION FACTOR (THETA)            1.0350
       BOD REMOVAL RATE AT ACTUAL TEMPERATURE           .03443
       TOTAL WASTE TO BE TREATED (FLOW)                  694.4 G.P.M.
       TOTAL WASTE TO BE TREATED (BOD)                  1800.0 LBS/DAY
       MINIMUM APPLICATION RATE                           1.00 G.P.M./SQ.FT.
       DEPTH OF TOWER                                     42.0 FEET
       'N' VALUE OF MEDIA CHOSEN                         1.000
       TOTAL REMOVAL EFFICIENCY REQUIRED                 95.00 %


               KINETIC MODEL CHOSEN WAS FIRST ORDER
               UNITS WERE SIZED ASSUMING 1,2,AND 3 STAGES


                             SINGLE STAGE   TWO STAGE      THREE STAGE

EFFICIENCY / STAGE (%)             95.00         77.64          63.00
APPLICATION RATE (GPM/SQ FT)        .483          .966          1.453
RECIRCULATION RATIO                 .000          .000           .000
VOLUME / STAGE (CU.FT.)          60359.0       30179.5        20077.3
STAGE VOLUME/ RAW FLOW,CF/GPM      86.92         43.46          28.91
TOTAL VOLUME (CUBIC FEET)        60359.0       60359.0        60232.0
NOMINAL FLOW PUMPED PER STAGE      694.4         694.4          694.4
TOTAL NOMINAL FLOW PUMPED          694.4        1388.8         2083.2
NUMBER OF PUMPING STATIONS             1             2              3


ORGANIC LOADINGS TO FILTER

  FOR 1 STAGE FILTRATION...
       ORGANIC LOAD TO FIRST FILTER                     29.822 LBS/DAY--1000CF

                           PARALLEL FILTERS             DIAMETER
                           PER STAGE                    PER STAGE
                                        1                     42.0 FEET
                                        2                     30.3 FEET
```

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                                      3                    24.7 FEET
                                      4                    21.4 FEET

   FOR 2 STAGE FILTRATION...
        ORGANIC LOAD TO FIRST FILTER                   59.643 LBS/DAY--1000CF
        ORGANIC LOAD TO SECOND FILTER                  13.337 LBS/DAY--1000CF

                          PARALLEL FILTERS           DIAMETER
                          PER STAGE                  PER STAGE
                                      1                    30.3 FEET
                                      2                    21.4 FEET
                                      3                    17.5 FEET
                                      4                    15.1 FEET
   FOR 3 STAGE FILTRATION...
        ORGANIC LOAD TO FIRST FILTER                   89.653 LBS/DAY--1000CF
        ORGANIC LOAD TO SECOND FILTER                  33.098 LBS/DAY--1000CF
        ORGANIC LOAD TO THIRD FILTER                   12.219 LBS/DAY--1000CF

                          PARALLEL FILTERS           DIAMETER
                          PER STAGE                  PER STAGE
                                      1                    24.7 FEET
                                      2                    17.4 FEET
                                      3                    14.2 FEET
                                      4                    12.3 FEET


                            SINGLE STAGE    TWO STAGE      THREE STAGE

EFFICIENCY / STAGE (%)              95.00          77.64          63.08
APPLICATION RATE (GPM/SQ FT)        1.000          1.000          1.453
RECIRCULATION RATIO                 4.854           .070           .000
VOLUME / STAGE (CU.FT.)          170734.0        31200.6        20113.0
STAGE VOLUME/ RAW FLOW,CF/GPM      245.87          44.03          28.06
TOTAL VOLUME (CUBIC FEET)        170734.0        62401.2        60338.9
NOMINAL FLOW PUMPED PER STAGE      4065.1          742.9          694.4
TOTAL NOMINAL FLOW PUMPED          4065.1         1485.7         2083.2
NUMBER OF PUMPING STATIONS              1              2              3


ORGANIC LOADINGS TO FILTER

   FOR 1 STAGE FILTRATION...
        ORGANIC LOAD TO FIRST FILTER                   10.543 LBS/DAY--1000CF

                          PARALLEL FILTERS           DIAMETER
                          PER STAGE                  PER STAGE
                                      1                    72.0 FEET
                                      2                    50.9 FEET
                                      3                    41.5 FEET
                                      4                    36.0 FEET

   FOR 2 STAGE FILTRATION...
        ORGANIC LOAD TO FIRST FILTER                   57.691 LBS/DAY--1000CF
        ORGANIC LOAD TO SECOND FILTER                  12.900 LBS/DAY--1000CF
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```
                         PARALLEL FILTERS       DIAMETER
                         PER STAGE              PER STAGE
                                       1              30.8 FEET
                                       2              21.8 FEET
                                       3              17.8 FEET
                                       4              15.4 FEET
   FOR 3 STAGE FILTRATION...
        ORGANIC LOAD TO FIRST FILTER            89.494 LBS/DAY--1000CF
        ORGANIC LOAD TO SECOND FILTER           33.039 LBS/DAY--1000CF
        ORGANIC LOAD TO THIRD FILTER            12.197 LBS/DAY--1000CF
                         PARALLEL FILTERS       DIAMETER
                         PER STAGE              PER STAGE
                                       1              24.7 FEET
                                       2              17.5 FEET
                                       3              14.9 FEET
                                       4              12.3 FEET
GENERAL DESIGN CRITERIA...
        BOD REMOVAL RATE AT 20 C                .03000
        ACTUAL TEMPERATURE                        22.0 C
        TEMPERATURE CORRECTION FACTOR (THETA)   1.0350
        BOD REMOVAL RATE AT ACTUAL TEMPERATURE  .03214
        TOTAL WASTE TO BE TREATED (FLOW)         694.4 G.P.M.
        TOTAL WASTE TO BE TREATED (BOD)         1800.0 LBS/DAY
        MINIMUM APPLICATION RATE                  1.00 G.P.M./SQ.FT.
        DEPTH OF TOWER                            21.0 FEET
        'N' VALUE OF MEDIA CHOSEN               1.000
        TOTAL REMOVAL EFFICIENCY REQUIRED        95.00 %


              KINETIC MODEL CHOSEN WAS SIMPLE RETARDENT
              UNITS WERE SIZED ASSUMING 1,2,AND 3 STAGES


                           SINGLE STAGE   TWO STAGE      THREE STAGE

EFFICIENCY / STAGE (%)            95.00         77.64          63.16
APPLICATION RATE (GPM/SQ FT)       .036          .194           .395
RECIRCULATION RATIO                .000          .000           .000
VOLUME / STAGE (CU.FT.)        410545.5       75024.7        36921.4
STAGE VOLUME/ RAW FLOW,CF/GPM    591.22        108.04          53.17
TOTAL VOLUME (CUBIC FEET)      410545.5      150049.5       110764.2
NOMINAL FLOW PUMPED PER STAGE     694.4         694.4          694.4
TOTAL NOMINAL FLOW PUMPED         694.4        1388.8         2083.2
NUMBER OF PUMPING STATIONS            1             2              3


ORGANIC LOADINGS TO FILTER

   FOR 1 STAGE FILTRATION...
        ORGANIC LOAD TO FIRST FILTER             4.384 LBS/DAY--1000CF
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                         PARALLEL FILTERS        DIAMETER
                         PER STAGE               PER STAGE
                                     1                157.8 FEET
                                     2                111.6 FEET
                                     3                 91.1 FEET
                                     4                 78.9 FEET

  FOR 2 STAGE FILTRATION...
       ORGANIC LOAD TO FIRST FILTER             23.992 LBS/DAY--1000CF
       ORGANIC LOAD TO SECOND FILTER             5.365 LBS/DAY--1000CF
                         PARALLEL FILTERS        DIAMETER
                         PER STAGE               PER STAGE
                                     1                 67.5 FEET
                                     2                 47.7 FEET
                                     3                 38.9 FEET
                                     4                 33.7 FEET
  FOR 3 STAGE FILTRATION...
       ORGANIC LOAD TO FIRST FILTER             48.752 LBS/DAY--1000CF
       ORGANIC LOAD TO SECOND FILTER            17.998 LBS/DAY--1000CF
       ORGANIC LOAD TO THIRD FILTER              6.645 LBS/DAY--1000CF
                         PARALLEL FILTERS        DIAMETER
                         PER STAGE               PER STAGE
                                     1                 47.3 FEET
                                     2                 33.5 FEET
                                     3                 27.3 FEET
                                     4                 23.7 FEET


                         SINGLE STAGE   TWO STAGE      THREE STAGE

EFFICIENCY / STAGE (%)           95.00       77.64          63.04
APPLICATION RATE (GPM/SQ FT)     1.000       1.000          1.000
RECIRCULATION RATIO             27.153       4.145          1.532
VOLUME / STAGE (CU.FT.)       410545.5     75024.7        36921.4
STAGE VOLUME/ RAW FLOW,CF/GPM   591.22      108.04          53.17
TOTAL VOLUME (CUBIC FEET)     410545.5    150049.5       110764.2
NOMINAL FLOW PUMPED PER STAGE  19549.8      3572.6         1758.2
TOTAL NOMINAL FLOW PUMPED      19540.8      7145.2         5274.5
NUMBER OF PUMPING STATIONS           1           2              3


ORGANIC LOADINGS TO FILTER

  FOR 1 STAGE FILTRATION...
       ORGANIC LOAD TO FIRST FILTER              4.384 LBS/DAY--1000CF

                         PARALLEL FILTERS        DIAMETER
                         PER STAGE               PER STAGE
                                     1                157.8 FEET
                                     2                111.6 FEET
                                     3                 91.1 FEET
```

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                                    4                78.9 FEET
FOR 2 STAGE FILTRATION...
     ORGANIC LOAD TO FIRST FILTER                 23.992 LBS/DAY--1000CF
     ORGANIC LOAD TO SECOND FILTER                 5.365 LBS/DAY--1000CF

                         PARALLEL FILTERS         DIAMETER
                         PER STAGE                PER STAGE
                                    1                   67.5 FEET
                                    2                   47.7 FEET
                                    3                   38.9 FEET
                                    4                   33.7 FEET
FOR 3 STAGE FILTRATION...
     ORGANIC LOAD TO FIRST FILTER                 48.752 LBS/DAY--1000CF
     ORGANIC LOAD TO SECOND FILTER                17.998 LBS/DAY--1000CF
     ORGANIC LOAD TO THIRD FILTER                  6.645 LBS/DAY--1000CF

                         PARALLEL FILTERS         DIAMETER
                         PER STAGE                PER STAGE
                                    1                   47.3 FEET
                                    2                   33.5 FEET
                                    3                   27.3 FEET
                                    4                   23.7 FEET
GENERAL DESIGN CRITERIA...
     BOD REMOVAL RATE AT 20 C                     .03214
     ACTUAL TEMPERATURE                             22.0 C
     TEMPERATURE CORRECTION FACTOR (THETA)        1.0350
     BOD REMOVAL RATE AT ACTUAL TEMPERATURE       .03443
     TOTAL WASTE TO BE TREATED (FLOW)             694.4 G.P.M.
     TOTAL WASTE TO BE TREATED (BOD)             1800.0 LBS/DAY
     MINIMUM APPLICATION RATE                      1.00 G.P.M./SQ.FT.
     DEPTH OF TOWER                                42.0 FEET
     'N' VALUE OF MEDIA CHOSEN                    1.000
     TOTAL REMOVAL EFFICIENCY REQUIRED            95.00 %


               KINETIC MODEL CHOSEN WAS SIMPLE RETARDENT
               UNITS WERE SIZED ASSUMING 1,2,AND 3 STAGES


                              SINGLE STAGE   TWO STAGE      THREE STAGE

EFFICIENCY / STAGE (%)            95.00          77.54          63.0
APPLICATION RATE (GPM/SQ FT)      .076           .416           .8
RECIRCULATION RATIO               .000           .000           .0
VOLUME / STAGE (CU.FT.)       383248.6        70036.4        34466.
STAGE VOLUME/ RAW FLOW:CF/GPM   551.91         100.86          49.6
TOTAL VOLUME (CUBIC FEET)     383248.6       140072.8       103399.
NOMINAL FLOW PUMPED PER STAGE    694.4          694.4          694.
TOTAL NOMINAL FLOW PUMPED        694.4         1388.8         2083.
NUMBER OF PUMPING STATIONS           1              2
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ORGANIC LOADINGS TO FILTER

  FOR 1 STAGE FILTRATION...
      ORGANIC LOAD TO FIRST FILTER                4.697 LBS/DAY--1000CF

                          PARALLEL FILTERS        DIAMETER
                          PER STAGE               PER STAGE
                                  1                   107.8 FEET
                                  2                    76.2 FEET
                                  3                    62.2 FEET
                                  4                    53.9 FEET

  FOR 2 STAGE FILTRATION...
      ORGANIC LOAD TO FIRST FILTER               25.701 LBS/DAY--1000CF
      ORGANIC LOAD TO SECOND FILTER               5.747 LBS/DAY--1000CF

                          PARALLEL FILTERS        DIAMETER
                          PER STAGE               PER STAGE
                                  1                    46.1 FEET
                                  2                    32.6 FEET
                                  3                    26.6 FEET
                                  4                    23.0 FEET
  FOR 3 STAGE FILTRATION...
      ORGANIC LOAD TO FIRST FILTER               52.225 LBS/DAY--1000CF
      ORGANIC LOAD TO SECOND FILTER              19.280 LBS/DAY--1000CF
      ORGANIC LOAD TO THIRD FILTER                7.118 LBS/DAY--1000CF

                          PARALLEL FILTERS        DIAMETER
                          PER STAGE               PER STAGE
                                  1                    32.3 FEET
                                  2                    22.9 FEET
                                  3                    18.7 FEET
                                  4                    16.2 FEET


                          SINGLE STAGE   TWO STAGE      THREE STAGE

EFFICIENCY / STAGE (%)            95.00        77.64          63.6
APPLICATION RATE (GPM/SQ FT)      1.000        1.000          1.00
RECIRCULATION RATIO              12.141        1.401          .10
VOLUME / STAGE (CU.FT.)        383248.6      70036.4       34466.
STAGE VOLUME/ RAW FLOW:CF/GPM    551.91       100.96          49.6
TOTAL VOLUME (CUBIC FEET)      383248.6     140072.8      103399.
NOMINAL FLOW PUMPED PER STAGE    9125.0       1667.5          820.
TOTAL NOMINAL FLOW PUMPED        9125.0       3335.1         2461.
NUMBER OF PUMPING STATIONS            1            2


ORGANIC LOADINGS TO FILTER

  FOR 1 STAGE FILTRATION...
      ORGANIC LOAD TO FIRST FILTER                4.697 LBS/DAY--1000CF
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                    PARALLEL FILTERS           DIAMETER
                    PER STAGE                  PER STAGE
                                1                   107.8 FEET
                                2                    76.2 FEET
                                3                    62.2 FEET
                                4                    53.9 FEET

     FOR 2 STAGE FILTRATION...
          ORGANIC LOAD TO FIRST FILTER         25.791 LBS/DAY--1000CF
          ORGANIC LOAD TO SECOND FILTER         5.747 LBS/DAY--1000CF

                    PARALLEL FILTERS           DIAMETER
                    PER STAGE                  PER STAGE
                                1                    46.1 FEET
                                2                    32.6 FEET
                                3                    26.6 FEET
                                4                    23.0 FEET
     FOR 3 STAGE FILTRATION...
          ORGANIC LOAD TO FIRST FILTER         52.225 LBS/DAY--1000CF
          ORGANIC LOAD TO SECOND FILTER        19.280 LBS/DAY--1000CF
          ORGANIC LOAD TO THIRD FILTER          7.119 LBS/DAY--1000CF

                    PARALLEL FILTERS           DIAMETER
                    PER STAGE                  PER STAGE
                                1                    32.4 FEET
                                2                    22.9 FEET
                                3                    18.7 FEET
                                4                    16.2 FEET


 @FIN
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APPENDIX

SUMMARY OF TRICKLING FILTER PLANE PERFORMANCE
WHEY AND SEWAGE

Summary of Trickling Filter Plane Performance
Whey and Sewage

Series #1

No nutrients
pH = 7.0

Run No.	Filter Geometry Angle (°)	Length (ft)	Area (SF)	Temperature (°C)	Hydraulic Conditions U' gpm/LF	Recycle Ratio	Soluble BOD_5 (ppm) Feed L_a	Effluent L_e	Soluble BOD_5 Removal (%)
1	45	9	.375	(29	.070	10	600	140	77
				(29	.070	10	600	140	77
2	45	9	.375	29	.095	2	570	380	33
3	45	9	.375	27	.111	1.67	570	380	33
4	45	9	.375	30	.123	1.1	620	485	22
5	30	9	.375	(22	.068	0	360	330	8
				(25	.065	0	500	420	16
6	30	9	.375	(20	.046	0	360	310	14
				(21	.045	0	620	480	23
7	30	9	.375	(28	.014	0	475	220	54
				(31	.014	0	440	140	68

(continued)

Series #2

Fe^{+3} as nutrient
pH = 7.0

Run No.	Filter Geometry Angle (°)	Filter Geometry Length (ft)	Filter Geometry Area (SF)	Temperature (°C)	Hydraulic Conditions U' gpm/LF	Hydraulic Conditions Recycle Ratio	Soluble BOD_5 (ppm) Feed L_a	Soluble BOD_5 (ppm) Effluent L_e	Soluble BOD_5 Removal (%)
1	45	9	.375	(29	.095	2	530	490	7.5
				(29	.095	2	600	390	35
				(30	.095	2	620	400	35
				(29	.095	2	570	390	32
2	45	9	.375	(27	.085	5	570	180	68
				(27	.079	4.2	490	220	55
3	30	9	.375	21	.065	0	620	470	24
4	30	9	.375	(28	.015	0	280	110	61
				(30	.013	0	320	170	47

(continued)

Series #3

N as nutrient
pH = 7.0

Run	Filter Geometry				Hydraulic Conditions		Soluble BOD_5 (ppm)		Soluble BOD_5
No.	Angle (°)	Length (ft)	Area (SF)	Temperature (°C)	U' gpm/LF	Recycle Ratio	Feed L_a	Effluent L_e	Removal (%)
1	45	9	.375	(29	.095	2	560	420	25
				(29	.095	2	600	310	48
				(30	.095	2	620	300	52
				(29	.095	2	570	300	47
2	45	9	.375	(27	.146	1.1	490	380	22
				(27	.142	.9	570	440	23

(continued)

Series #4

Fe^{+3} and N as nutrient
pH = variable

Run No.	Filter Geometry Angle (°)	Filter Geometry Length (ft)	Filter Geometry Area (SF)	Temperature (°C)	Hydraulic Conditions U' gpm/LF	Hydraulic Conditions Recycle Ratio	Soluble BOD_5 (ppm) Feed L_a	Soluble BOD_5 (ppm) Effluent L_e	BOD_5 Removal (%)
1 pH=4.5	45	9	.375	(29	.11	2.2	640	240	63
				(24	.082	2.25	600	310	48
2 pH=4.8	45	9	.375	29	.091	2.3	480	170	65
3 pH=5.7	45	9	.375	24	.099	2.4	720	370	-
4 pH=9.8	45	9	.375	24	.10	1.7	670	510	-

(continued)

Series #5

Fe^{+3} and N as nutrients
Plane angle variable

Run No.	Filter Geometry			Temperature (°C)	Hydraulic Conditions		Soluble BOD_5 (ppm)		Soluble BOD_5 Removal (%)
	Angle (°)	Length (ft)	Area (SF)		U' gpm/LF	Recycle Ratio	Feed L_a	Effluent L_e	
1	45	9	.375	29	.095	2	560	300	46
				29	.095	2	600	250	58
				30	.095	2	620	270	56
				29	.095	2	560	430	23
				28	.095	2	550	320	42
2	45	9	.375	21	.095	2	720	410	43
3	45	9	.375	31	.086	0	270	230	15
4	45	9	.375	27	.073	0	490	135	72
5	45	9	.375	28	.039	0	540	330	39
6	45	9	.375	31	.023	0	540	220	59
				31	.023	0	600	190	68
				29	.019	0	270	125	54

(continued)

Series #6

Fe^{+3} and N as nutrients
Plane angle variable

Run No.	Filter Geometry Angle (°)	Length (ft)	Area (SF)	Temperature (°C)	Hydraulic Conditions U' gpm/LF	Recycle Ratio	Soluble BOD$_5$ (ppm) Feed L_a	Effluent L_e	Soluble BOD$_5$ Removal (%)
1	30	9	.375	25	.090	6.1	530	160	70
2	30	9	.375	(25	.086	2.5	530	290	45
				(23	.081	2.4	580	260	55
3	30	9	.375	22	.077	3.3	580	260	55
4	30	9	.375	25	.071	0	530	430	19
5	30	9	.375	23	.070	.5	580	380	34
6	30	9	.375	(27	.068	0	450	360	20
				(26	.065	0	490	390	20
7	30	9	.375	23	.067	0	580	500	14
8	30	9	.375	(27	.049	0	490	330	33
				(28	.047	0	450	330	27
				(29	.047	0	500	400	20
9	30	9	.375	29	.025	0	490	200	59

(continued)

Series #6 (continued)

Fe^{+3} and N as nutrients
Plane angle variable

	Filter Geometry				Hydraulic Conditions		Soluble BOD_5 (ppm)		Soluble BOD_5
Run No.	Angle (°)	Length (ft)	Area (SF)	Temperature (°C)	U' gpm/LF	Recycle Ratio	Feed L_a	Effluent L_e	Removal (%)
10	30	9	.375	(29	.021	0	490	150	69
				(27	.020	0	500	200	60
				(29	.018	0	450	150	67
11	30	18	.75	22	.076	2.2	390	85	78
12	30	18	.75	(28	.027	0	390	26	93
				(26	.025	0	380	110	71
12a	30	9	.375	(26	.025	0	380	280	26
				(26	.025	0	280	110	61
13	30	18	.75	(24	.024	0	400	80	80
				(24	.024	0	550	140	75

(continued)

Series #6 (continued)

Fe^{+3} and N as nutrients
Plane angle variable

Run No.	Filter Geometry Angle (°)	Filter Geometry Length (ft)	Filter Geometry Area (SF)	Temperature (°C)	Hydraulic Conditions U' gpm/LF	Hydraulic Conditions Recycle Ratio	Soluble BOD_5 (ppm) Feed L_a	Soluble BOD_5 (ppm) Effluent L_e	Soluble BOD_5 Removal (%)
13a	30	9	.375	(24	.024	0	400	200	50
				(24	.024	0	195	80	59
				(24	.024	0	550	270	51
				(24	.024	0	240	140	42
14	30	18	.75	20	.023	0	550	160	71
14a	30	9	.375	(20	.023	0	550	290	47
				(20	.023	0	270	160	41

1 *Accession Number*

W

2 *Subject Field & Group*

05D

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 *Organization*

QUIRK, LAWLER & MATUSKY ENGINEERS

6 *Title*

WHEY EFFLUENT PACKED TOWER TRICKLING FILTRATION

10 *Author(s)*

T. P. QUIRK
J. J. ZAMBRANO
J. HELLMAN

16 *Project Designation*

12130 DUJ (11060 DUJ)

21 *Note*

22 *Citation*

23 *Descriptors (Starred First)*

Biological Treatment, *Computer Programs, *Cost Allocation, *Dairy Industry, *Design Criteria, *Estimated Costs, *Mathematical Models, *Model Studies, *Sewage, *Sewage Treatment, *Trickling Filtration, *Capital Costs, Centrifugation, Hydrogen ion Concentration, Neutralization, Nutrients, Odor, Operating Costs, Pilot Plants, Separation Techniques, Sewers, Sludge Treatment, Temperature, Water Quality

25 *Identifiers (Starred First)*

Whey, *Chemical Treatment, Clarification, Detention Time, Recycle Sludge Conditioning, Thickening, Vacuum Filtration

27 *Abstract*

An analysis of BOD removal during flow over an inclined plane and through full-scale trickling filter media is developed and verified.

A defined scale-up procedure is used to calculate the full-scale reaction rate from the laboratory rate. The former varies with the packing used, the latter is constant.

The treatability of whey effluents is demonstrated by comparison with other industrial effluents, using a Surfpac-like medium in packed towers. A computer program is described, handling series or parallel filtration using one to three stages.

Ranges of operating parameters tested were: BOD 200 to 600 ppm; pH 4.5 to 9.8; temperature 15 to 30°C. Filter performance responded primarily to flow changes. Secondary sludge can be thickened by gravity compaction, and dewatered by vacuum filtration. Centrifugation is not effective.

In comparison, the activated sludge process requires an organic loading less than 0.1 lb. BOD/lb. sludge/day to maintain an SVI under 200, operation is sensitive to all parameters, and neither vacuum filtration nor centrifugation is effective for sludge dewatering.

Process designs and cost analyses are developed for a combination of whey and domestic sewage as follows: flow - 1.17 mgd; BOD - 6,900 lbs/day; suspended solids - 1,600 lbs/day.

Abstractor T.P. QUIRK

Institution QUIRK, LAWLER AND MATUSKY ENGINEERS

WR:102 (REV JULY 1969)
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